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CONTENTS

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THE DAILY VARIATION OF IRREGULAR DISTURBANCES OF THE EARTH'S MAGNETIC FIELD AT BOMBAY

BY R. NARAYANASWAMI*

Abstract—Besides the quiet-day solar diurnal variation and the variations associated with magnetic storms, the intensity of the Earth's magnetic field at any place is subject to many irregular, short-period fluctuations. The paper contains an analysis of the diurnal variation of these irregular disturbances during the eleven-year period 1923-33. As a measure of the disturbance, the departures of the hourly ranges of the horizontal forces from the mean hourly range on the five international quiet days in that particular month were used. In calculating the disturbance, due regard was paid to the sign of the change of the element during the hour. The diurnal variations of the irregular disturbances depend on the season of the year and on the sunspot-activity. These variations are analyzed and compared with the results of disturbance diurnal variation in higher latitudes. The main conclusions that emerge from the analysis are:

(*i*) The hour of minimum disturbance occurs early in the morning usually between 04^h to 05^h or 05^h to 06^h local time and that of the maximum near about noon.

(*ii*) There are two secondary maxima, one at 16^h to 18^h and another at about 22^h to 23^h local time.

(*iii*) Analyzing the results according to month, the day maximum is most pronounced in the months April to August. In the winter months, there is a tendency for the variation to approach the European type (as shown by the analysis of the data of Eskdalemuir (magnetic latitude $\Phi = 59°.5$) and of Wilhelmshaven ($\Phi = 54°.5$) in which there is one minimum in the morning at about 09^h local time and a maximum in the evening at about 22^h.

(*iv*) If days of magnetic character 2 are excluded, the diurnal variations are similar, but the late evening maximum is suppressed, leaving the noon maximum more pronounced.

It is generally believed that "in the latitudes between the two auroral zones, that is, up to at least 65° magnetic latitude, D_i has a simple diurnal variation with its maximum in the evening; as the auroral zone is approached the hour of maximum gets later, from about 21^h at 55° to midnight at 70°. Up to this latitude the form of the daily variation of D_i does not vary much either with season or with the general intensity of magnetic disturbance" [Chapman]. The present analysis of the Bombay data shows that in low magnetic latitudes, the main variation is a maximum near noon with a minimum a little before sunrise. The evening maximum of temperate latitudes is superposed on this simple variation.

It is suggested that the maxima of disturbance-variation at Bombay at about noon and in the afternoon are associated with the maxima of ion-density in the E- and F_1-layers and in the F_2-layer, respectively. The late evening maximum is presumably due to fluctuations in F_2-layer caused by electrified particles from the Sun concentrating on the night side of the Earth on account of the deflecting action of its magnetic field.

INTRODUCTION

In addition to the definitely classifiable types of magnetic disturbances such as magnetic storms and disturbances associated with radio fade-

*Part of a thesis approved for the degree of Master of Science of the Bombay University.

outs, there are other unclassified irregular disturbances, some of them being similar to gustiness or squalliness in an anemogram, which occur mostly on days of character 1 and 2. In recent years, considerable attention has been given to the diurnal variation of the irregular fluctuations in middle and high latitudes and some interesting generalizations have been obtained, notably by Stagg [see 1 of "References" at end of paper]. It is the purpose of the present note to discuss the results of a study of the irregular disturbance fluctuations of the magnetic field from the records of the Alibag Observatory, Bombay. Ordinarily, the quantity studied is the average value of the fluctuations of a magnetic element at a particular hour over a large number of days. There is no uniformity of practice as regards the adoption of a measure for hourly disturbance. One common method is to assign a character-figure to each hour of the day, somewhat in the same manner as character-figures are assigned to whole days. Another method is to obtain the average ranges of the magnetic element considered in any particular hour and either use them as such or combine them as Hr_H or Zr_Z or (Hr_H+Zr_Z). In high latitudes, owing to the large value of Z compared to that of H, it would not matter much whether Zr_Z or (Hr_Z+Zr_Z) is used and similarly in low latitudes, Hr_H would serve nearly as well as (Hr_H+Zr_Z). (Here, H and Z stand for the horizontal and vertical components of the Earth's magnetic field and r_H and r_Z for the ranges of H and Z during the time-interval.)

Analyzing the available data for the diurnal variation of magnetic disturbance for magnetic latitudes ranging from 54°.5 north to the north magnetic pole, Stagg [2] has shown that D_i, the average value of the fluctuations over a considerable length of time, is controlled by local time over this range of latitude. Between magnetic latitudes 55° and 69° north, D_i has a single maximum in the late evening, the time of maximum being about 21^h at 55° and gradually increasing to 24^h at 69°. The time of minimum is in the forenoon between 09^h and noon. Beyond 75°, a pronounced forenoon *maximum* appears. It is generally considered that "in the latitudes between the two auroral zones, that is, up to at least 65° magnetic latitude, D_i has a simple daily variation, with its maximum in the evening" [Chapman, The Earth's magnetism, p. 98]. Stagg found that the diurnal-variation curves of Hr_H and Zr_Z are similar in shape and quite different from the regular diurnal variations of H and of Z. He also showed that Hr_H- and Zr_Z-curves cannot be regarded as curves of time differential of the quiet-day solar diurnal variation in H and Z. There are however very few investigations of the diurnal variation of D_i in low latitudes, and an examination of the Bombay magnetic data was therefore undertaken to verify whether the above statement holds without modification for low latitudes also.

SCOPE AND METHOD OF THE PRESENT INVESTIGATION

In the following paper, the results are given of an analysis of the irregular disturbances shown in the magnetograms of the horizontal component of the Earth's magnetic field obtained at Alibag during the years 1923 to 1933. The vertical-force magnetograms also were analyzed similarly for a shorter period, namely, the two years, 1923 and 1933. The first question that arises is, how should an irregular disturbance be meas-

ured? The method of assigning character-figures to each hour was tried, but it was later given up in favor of an objective method. From the very first it was evident that Hr_H (or Zr_Z), which had been used as a measure of disturbance in high latitudes, would not give a suitable measure of the irregular disturbance in Bombay, as the regular quiet-day hourly ranges were, in some parts of the day, so large that their contribution to Hr_H would be comparable in magnitude to the irregular disturbances and could not therefore be ignored. This will be obvious from Figure 1 in which the mean hourly values of Hr_H in each of the seasons, November to February

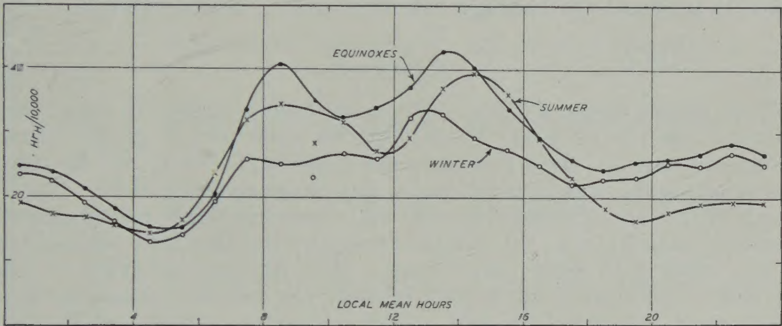

FIG. 1—DIURNAL VARIATION OF Hr_H AT ALIBAG

(winter), May to August (summer), and March, April, September, and October (equinoxes) are plotted. The maxima in the curves occur near the hours when the normal rate of change of H with time is maximum. No doubt, the comparatively larger values of Hr_H in the first half of the night than in the second half are an indication of the greater disturbedness in that period, but it is clear that in general before the diurnal variation of the irregular disturbances can be obtained with any degree of purity, the effect of the regular diurnal variation should first be eliminated. The method of analyzing the data that was adopted is as follows.

The hourly ranges were tabulated from the original magnetograms for each hour of all the days of the eleven years 1923-33. The regular variation was then eliminated from the total variation in order to get the disturbance-variation. The regular variation was taken to be the mean variation in that particular hour on the five international quiet days in the month. As we have to take the difference between two variations, the sign of the variation has to be taken into account. The convention was adopted of calling the variation positive if the value of H increased with time and negative if it decreased. Thus if in an hour in which the normal quiet day variation was $+\triangle H_1$ the actual range of H during the hour was $+\triangle H$ (positive sign if the later end of swing was on the side of increasing H), the disturbance-variation during the hour was considered to be $(\triangle H-\triangle H_1)$. It usually happened that the correction $\triangle H_1$ required during the night hours, namely, 18^h to 06^h, was negligible to the order of accuracy with which the measurements of range were made.

In averaging the *disturbances* over a period of time—for example, a month, season, or year—no further account was taken of the sign of the disturbance.

It will be obvious that while this method of estimation will take account of disturbances occurring *within* periods of one hour, it will not take account of the slower (and also often bigger) variations such as are associated with magnetic storms.

The data were then analyzed according to month, season, and mean solar activity of the year. Similarly the fluctuation on all days, on days of small disturbance (character 0 and 1), and on days of large disturbance (character 2) was separately determined. The results of the analysis were compared with results of similar analysis made in higher latitudes and an attempt was made to explain the reason for the peculiarities observed, in terms of the changes taking place in the ionosphere.

Results

Mean hourly ranges of Hr_H—The mean hourly ranges of $Hr_H \times 10{,}000$ (mean for the eleven years 1923-1933) for each month of the year, for each season, and for the whole year are given in Table 1. As the chart of the magnetograph was changed every day between 09^h and 10^h, there was a break in the record in this interval and ranges in this interval cannot be considered satisfactory; the tabulated values for this hour should therefore be taken with some reservation. The diurnal-variation curves of Hr_H given in Figure 1 show clearly that the hourly ranges have their maximum in the forenoon and afternoon hours, a fact which may be expected from the nature of the diurnal variation of H. The larger values of Hr_H during the earlier half of the night than in the later half are due to the greater number and intensity of the irregular disturbances during the former period. As regards the seasonal variation, the hourly ranges have their maximum values in the equinoctial months. Comparing summer and winter, the day ranges are greater in summer and the night ranges in winter.

Diurnal variation in the mean of the year and in each season—The hourly mean values of $(r_H - r_{Hq})$, that is, hourly range on any day minus the range on a quiet day, are given for each month, for each season, and for the whole year in Table 2. The diurnal-variation curves of this quantity for each of the three seasons summer, winter, and equinoxes are drawn in Figures 2, 3, and 4. The tabulated figures and the diagrams bring out the following points:

(1) The disturbance of the normal course of variation of H is least marked one or two hours before sunrise.

(2) The disturbance-curves show a pronounced maximum at about noon, another maximum at 16^h to 18^h, and a third one between 20^h and 24^h. It will be noticed that the noon maximum of $(r_H - r_{Hq})$ does not coincide with either of the maxima in the curve of variation of Hr_H. The noon maximum is most pronounced in summer and the night maximum in winter.

Diurnal variation of irregular disturbance on days of different magnetic characters—It is *a priori* evident that on days of character 2, the irregular disturbance will be greater at all hours than on the normal day. But it is not possible to say without investigation which of the maxima will be most enhanced on disturbed days. With a view to studying this, the days were separated into days of character 0, 1, and 2 and the hourly means of $(r_H - r_{Hq})$ were found for days of character 0 and 1 together and

TABLE 1—*Mean monthly, seasonal, and annual hourly means in γ^2 of ($Hr_H \times 10{,}000$), 1923-1933*

Hour, local time	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Mean for year	Jan, Feb, Nov, Dec	Mar, Apr, Sep, Oct	May, Jun, Jul, Aug
h h																
00–01	23	26	26	22	22	17	17	19	24	29	21	24	23	23	25	19
01–02	23	26	23	21	19	16	16	19	23	27	19	22	21	23	24	17
02–03	19	23	22	16	17	17	17	16	22	23	15	18	19	19	21	17
03–04	18	18	20	16	18	16	13	15	18	18	13	15	17	16	18	15
04–05	15	15	16	15	14	13	16	12	15	16	11	12	14	13	15	14
05–06	15	16	16	14	16	17	17	14	15	17	13	13	15	14	15	16
06–07	17	18	19	20	26	25	25	18	22	21	24	19	21	19	20	23
07–08	23	28	36	39	37	32	33	26	28	32	32	24	31	26	34	32
08–09	23	27	39	46	35	34	36	33	42	38	29	23	33	25	41	35
09–10	26	25	34	34	29	27	31	27	29	29	21	22	28	23	31	29
10–11	32	29	33	28	32	31	34	32	33	36	24	24	31	27	32	32
11–12	26	23	26	28	26	26	26	26	27	28	25	23	26	24	27	26
12–13	32	32	37	36	31	29	27	30	31	45	35	31	33	33	37	29
13–14	33	34	42	43	38	37	36	38	37	50	35	30	38	33	43	37
14–15	29	32	41	40	37	43	41	37	37	43	29	26	36	29	40	39
15–16	27	31	34	33	32	38	41	32	34	35	26	26	33	27	34	36
16–17	23	29	29	29	28	30	31	28	29	31	24	23	28	25	29	29
17–18	21	24	25	24	25	23	21	23	24	31	21	21	24	22	26	23
18–19	23	25	25	22	20	17	18	19	23	26	21	22	22	23	24	19
19–20	23	23	27	20	17	17	15	16	26	29	23	23	22	23	26	16
20–21	25	26	29	23	20	19	16	17	25	28	25	26	23	25	26	18
21–22	25	28	27	23	23	16	18	19	27	31	23	25	24	25	27	19
22–23	26	32	29	24	22	17	17	20	27	34	24	25	25	27	29	19
23–24	26	28	27	24	22	18	16	20	25	32	21	26	24	25	27	19

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The data were then analyzed according to month, season, and mean solar activity of the year. Similarly the fluctuation on all days, on days of small disturbance (character 0 and 1), and on days of large disturbance (character 2) was separately determined. The results of the analysis were compared with results of similar analysis made in higher latitudes and an attempt was made to explain the reason for the peculiarities observed, in terms of the changes taking place in the ionosphere.

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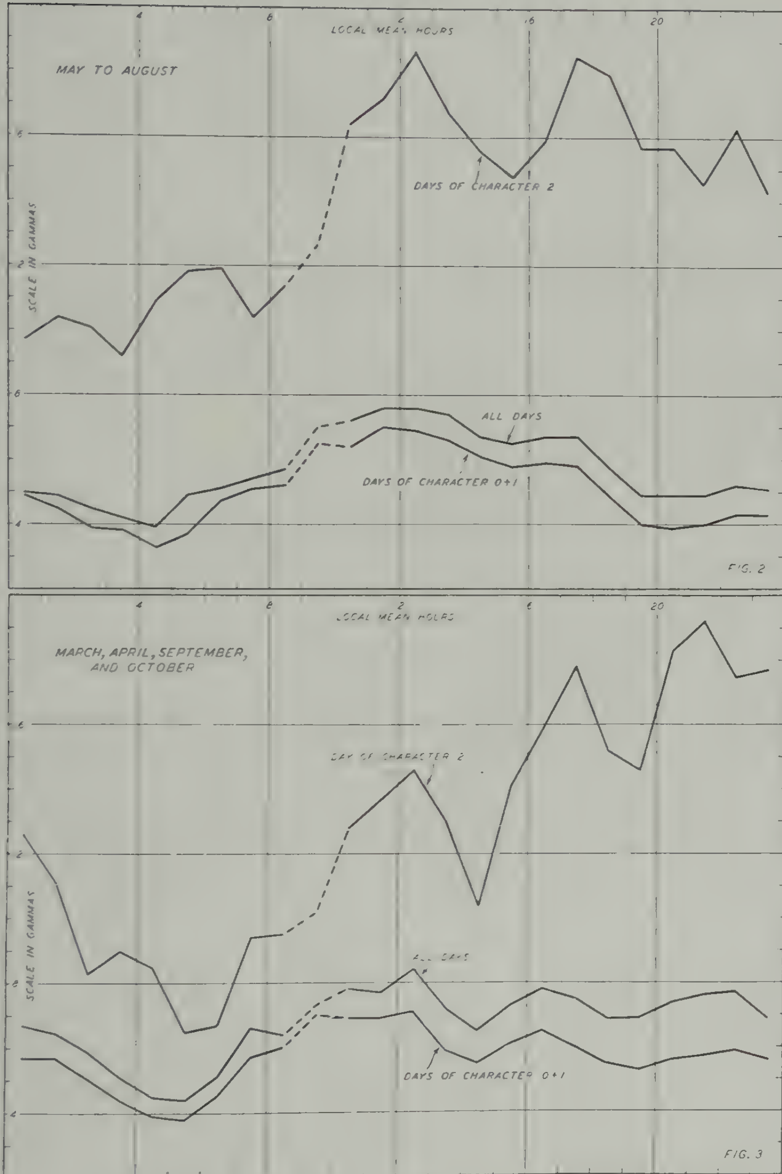

FIGS. 2 AND 3—DIURNAL VARIATION OF IRREGULAR DISTURBANCE OF H AT BOMBAY

for days of character 2. Among days of character 0 and 1, obviously the disturbances on days of character 1 will contribute more to the average disturbance. The mean hourly values of $(r_H - r_{Hq})$ on days of character 0 and 1 and on days of character 2 for each month and season are given in Tables 3 and 4. The Figures 2, 3, and 4, in which the diurnal variations on days of different magnetic character are plotted, show that

TABLE 3—*Mean hourly values in γ of* $(r_H - r_{Hq})$ *on days of character 0 and 1, 1923-1933*

Hour, local time	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Mean for year	Jan, Feb, Nov, Dec	Mar, Apr, Sep, Oct	May, Jun, Jul, Aug
h h																
00–01	5.9	6.8	5.9	5.2	5.5	5.0	4.3	4.9	5.9	5.6	5.4	5.6	5.5	5.9	5.7	4.9
01–02	5.7	6.5	6.1	5.4	4.8	4.7	4.0	4.6	5.3	5.8	4.7	4.7	5.2	5.4	5.7	4.5
02–03	4.6	5.9	5.5	4.6	3.6	4.3	4.2	3.7	5.2	5.3	4.5	4.8	4.7	5.1	5.1	3.9
03–04	4.3	4.3	4.7	4.1	4.0	4.3	3.4	3.4	4.7	4.3	4.1	4.1	4.1	4.2	4.4	3.8
04–05	3.7	4.1	4.9	3.5	3.7	3.7	3.1	2.7	3.7	3.4	2.9	3.1	3.6	3.5	3.9	3.3
05–06	3.4	3.9	4.5	3.5	3.9	3.9	3.7	3.1	3.5	3.8	3.5	3.5	3.7	3.5	3.8	3.7
06–07	3.5	4.3	4.1	4.6	5.1	4.6	4.3	4.5	5.3	4.1	4.9	4.4	4.5	4.4	4.5	4.7
07–08	4.4	4.7	4.8	6.2	5.5	4.9	4.7	5.2	5.8	5.9	4.3	5.0	5.1	4.6	5.7	5.1
08–09	4.3	4.9	4.9	6.3	4.7	5.3	4.9	5.9	7.6	5.2	4.6	5.2	5.3	4.7	6.0	5.2
09–10	4.8	6.0	6.1	7.9	6.4	6.8	5.9	7.0	7.8	6.1	6.1	4.6	6.3	5.4	7.0	6.5
10–11	6.4	5.2	5.5	9.2	6.9	6.3	6.4	6.1	6.9	5.7	5.1	5.1	6.3	5.5	6.9	6.4
11–12	7.3	6.5	7.4	7.2	7.1	7.5	6.8	6.6	6.2	6.6	6.9	5.8	6.8	6.6	6.9	7.0
12–13	6.7	7.1	7.6	7.2	6.9	6.3	6.8	7.3	6.6	7.2	7.4	5.1	6.8	6.6	7.1	6.9
13–14	6.7	6.2	5.9	5.9	6.4	6.4	7.1	6.7	6.4	5.6	4.5	4.7	6.1	5.5	5.9	6.6
14–15	6.0	5.3	5.0	5.4	5.9	6.3	6.1	5.8	5.5	5.4	5.5	5.7	5.7	5.6	5.5	6.1
15–16	5.3	5.8	6.0	6.0	6.2	6.1	5.3	5.6	6.1	6.1	6.2	5.2	5.8	5.6	6.1	5.8
16–17	5.5	6.6	6.7	6.2	6.0	6.1	5.8	5.8	6.3	6.6	5.8	5.3	6.1	5.8	6.5	5.9
17–18	5.5	6.1	6.5	6.2	5.8	5.8	6.0	5.7	5.6	5.9	6.3	5.9	5.9	5.9	6.0	5.8
18–19	5.1	5.7	6.1	5.2	5.0	4.6	4.9	5.0	5.3	5.4	4.4	5.0	5.2	5.1	5.5	4.9
19–20	5.1	6.0	5.4	5.2	3.9	4.2	3.5	4.4	5.1	5.2	5.1	4.8	4.8	5.2	5.3	4.0
20–21	5.5	5.7	6.3	5.1	3.8	4.4	3.7	3.8	5.4	5.5	6.4	5.7	5.1	5.8	5.6	3.9
21–22	5.5	6.6	6.2	4.6	4.0	3.8	3.7	4.5	6.0	6.1	5.6	5.5	5.2	5.8	5.7	4.0
22–23	5.5	7.0	5.7	5.0	4.5	4.0	4.3	4.3	6.0	6.8	5.4	5.5	5.3	5.9	5.9	4.3
23–24	5.1	6.8	5.7	5.8	4.4	4.3	4.1	4.5	5.2	5.8	5.5	4.9	5.2	5.6	5.6	4.3
No. days	304	270	294	294	310	310	318	315	282	284	303	309	3593	......	......	......

TABLE 4—*Mean hourly values in* γ *of* $(r_H - r_{Hq})$ *on days of character 2, 1923-1933*

Hour, local time	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Mean for year	Jan, Feb, Nov, Dec	Mar, Apr, Sep, Oct	May, Jun, Jul, Aug
h h																
00–01	9.5	9.3	11.4	10.7	8.8	7.4	9.2	13.3	10.3	18.2	9.3	14.9	11.0	10.8	12.6	9.7
01–02	11.3	10.1	9.7	9.9	11.0	9.4	9.4	11.6	10.8	13.9	10.3	10.9	10.7	10.7	11.1	10.4
02–03	8.8	10.7	10.1	8.0	11.7	8.1	9.6	10.9	13.7	11.5	5.6	9.9	9.0	8.7	8.3	10.1
03–04	8.1	10.8	9.0	9.6	7.4	9.2	9.6	10.4	8.5	9.1	6.4	7.7	8.8	8.2	9.0	9.2
04–05	10.4	11.5	8.6	9.4	7.2	4.9	19.7	11.6	6.1	9.8	6.8	5.5	9.3	8.5	8.5	10.9
05–06	8.8	6.7	6.8	4.8	8.7	9.1	16.2	13.3	5.1	9.2	6.8	6.2	8.5	7.1	6.5	11.8
06–07	8.9	7.3	6.2	5.8	10.0	6.9	18.2	12.3	5.4	9.3	7.6	7.0	8.8	7.7	6.7	11.9
07–08	8.2	9.9	10.1	10.0	7.4	9.4	13.1	11.6	10.0	9.4	10.8	6.3	9.5	8.8	9.4	10.4
08–09	5.4	8.4	10.9	7.7	11.7	8.2	17.4	8.5	12.2	7.4	6.8	7.9	9.4	7.7	9.5	11.4
09–10	5.7	8.1	7.6	12.5	14.5	9.8	16.8	9.9	11.5	9.3	9.5	6.5	10.1	7.5	10.2	12.7
10–11	9.3	11.7	10.6	12.2	17.7	14.5	16.6	16.6	16.2	12.1	10.3	10.3	13.2	10.4	12.8	16.4
11–12	9.3	13.1	13.5	15.8	12.0	13.8	22.9	20.2	10.8	14.5	12.8	10.3	14.1	11.4	13.7	17.2
12–13	12.2	9.3	13.1	14.6	16.8	21.5	19.6	16.4	12.3	18.5	13.0	9.3	14.7	10.9	14.6	18.6
13–14	10.3	13.1	9.8	13.5	16.0	17.2	13.1	21.2	13.2	16.5	9.6	9.0	13.4	10.5	13.0	16.8
14–15	10.0	8.8	7.1	13.0	14.8	17.0	16.6	14.0	14.3	15.2	11.8	13.1	12.3	10.9	10.4	15.6
15–16	14.0	11.1	10.0	15.6	14.6	16.5	16.5	11.4	12.1	18.8	16.4	12.9	14.2	13.6	14.1	14.8
16–17	12.2	13.9	14.5	16.2	14.0	17.2	16.6	15.9	15.5	17.2	15.9	15.0	15.4	14.3	15.9	15.9
17–18	11.0	15.6	14.4	13.0	15.8	21.2	18.8	18.1	21.8	22.0	14.4	12.8	16.6	13.5	17.8	18.5
18–19	13.4	12.6	13.9	13.9	20.4	13.2	19.0	19.5	13.8	19.3	23.0	15.3	16.4	16.1	15.2	18.0
19–20	16.9	15.6	18.2	12.7	16.9	16.5	14.3	15.2	20.9	16.5	17.4	15.2	15.5	16.3	14.6	15.7
20–21	15.5	16.8	19.4	14.6	19.2	14.1	16.7	12.9	19.8	19.5	22.4	19.0	17.4	18.4	18.3	15.7
21–22	17.1	13.2	19.6	17.1	16.9	12.9	14.5	14.2	20.8	19.1	15.8	17.4	16.6	15.9	19.2	14.6
22–23	19.5	23.7	17.0	14.9	18.1	15.0	16.3	15.9	15.3	23.0	20.3	15.7	17.9	19.8	17.5	16.3
23–24	19.4	17.6	19.0	14.6	17.8	14.3	10.4	14.5	17.6	19.8	14.7	18.0	16.4	17.4	17.7	14.3
No. days	37	41	47	36	31	20	23	26	48	57	27	32	425	......	......	......

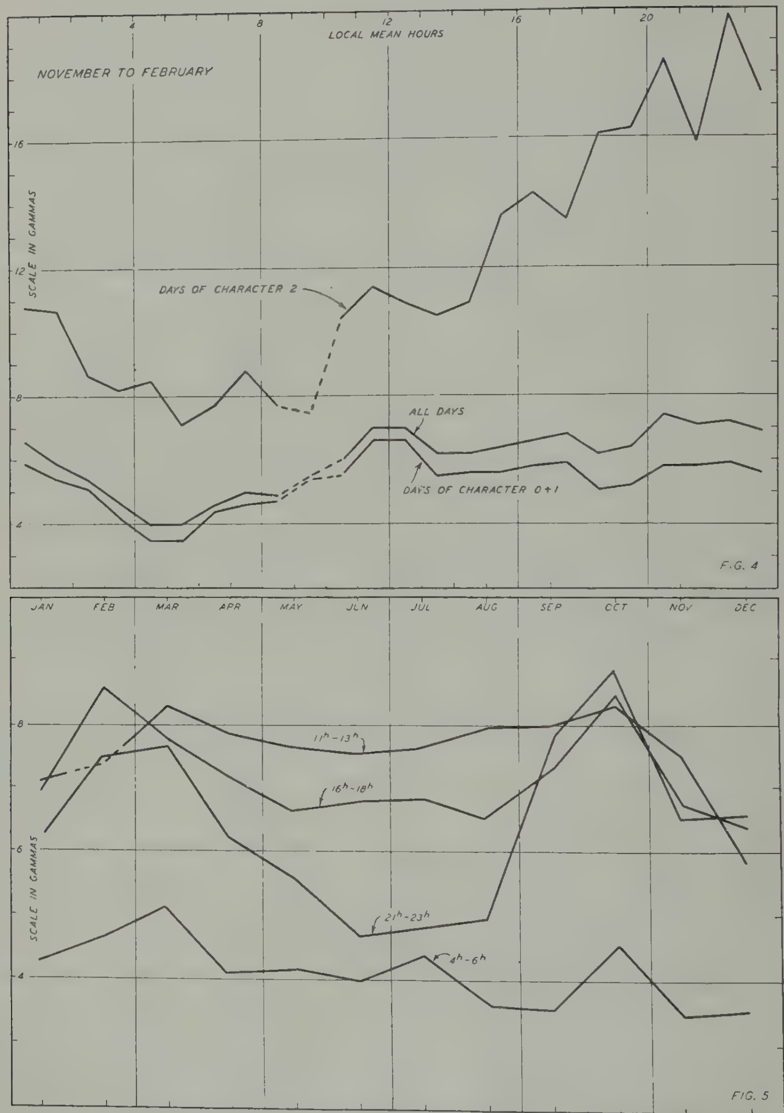

FIG. 4—DIURNAL VARIATION OF IRREGULAR DISTURBANCE OF H AT BOMBAY
FIG. 5—ANNUAL VARIATION OF IRREGULAR DISTURBANCE AT DIFFERENT TIMES OF DAY

in every season, the effect of magnetic disturbance is to cause an increase in range in all hours, but particularly so in the pre-midnight hours; the smallest increase is in the hours near noon.

Annual variation of disturbance—It is well known that there is a regular annual variation of magnetic activity. Taking the mean day-to-day changes of magnetic field as a measure of activity, the magnetic activity of the Earth as a whole shows two distinct maxima during the year, one in March and the other in October [3]. If we take the mean hourly dis-

turbance as a measure of the activity at Bombay, we get the annual variation of activity represented by the curves shown in Figure 5. In this Figure four curves have been drawn showing the disturbance at 04^h to 06^h, 11^h to 13^h, 16^h to 18^h, and 21^h to 23^h. While all of them show maxima in February or March and October, the minimum which occurs in summer is more marked at 16^h to 18^h than at 11^h to 13^h and more at 21^h to 23^h than at 16^h to 18^h. This suggests that the agency responsible for the maximum disturbance in the pre-midnight hours of the night is the same as the agency which causes the maxima of disturbance in these two months.

Dependence of disturbance on solar activity—In Table 5 are given the mean values of the disturbance in each of the years 1923-33. As may be expected, the mean disturbance is greater in years of large sunspot-frequency (for example, 1926 to 1929) than in years of small sunspot-frequency (1923, 1924, 1932, and 1933), but the same three epochs of maximum disturbance are shown (Fig. 6). The excess of hourly disturbance in years of maximum sunspots over that in years of minimum sunspots is greatest twice a day—once at about noon and another time at about 20^h in the evening.

Positive and negative disturbances—So far, we have not taken any account of whether the disturbance is in the direction of increasing the north component of the horizontal force or of decreasing it. A rough analysis of the disturbances according to their signs, shows that disturbances increasing H are most frequent during night hours and those decreasing it during day hours. An analysis of Bombay observations made by Chambers [4] many years ago throws a good deal of light on this question. His method of analysis was somewhat different from that adopted here. It may best be described in his own words: "The hourly directions of the magnet (or values of H) are entered in monthly tables, having the days of the month in successive horizontal lines and the hours of the day in vertical columns. On inspecting any such monthly table, it is at once seen that a considerable portion of the entries in the several columns differs considerably from their respective means or 'first normals' and must be regarded as 'disturbed' observations. The laws of their relative frequency and amount of disturbance in different years, months, and hours are then sought out, by separating for that purpose a sufficient body of the most disturbed observations, computing the amount of departures in each case from the normal of the same month and hour, and arranging the months in annual, monthly, and hourly tables. In making these computations, the first normals require themselves to be corrected by the omission in each vertical column of the entries noted as disturbed . . ." The disturbances tabulated by Chambers include therefore all those hourly values which differed from the "quiet" hourly mean for that particular hour of the month by a certain arbitrary amount either in excess or in defect. In Figure 7 (based on data given by Chambers in Tables 90 and 91 of his memoir) is shown the aggregate of all the disturbances of horizontal intensity in which (1) the deviations from the "undisturbed normal" mean were positive and (2) the deviations from the "undisturbed normal" mean were negative; curves are given for two periods November to February and May to August. It will be seen that disturbances with positive deviations were a maximum in the daytime at about noon while those with negative deviations had three maxima in winter, one at about

TABLE 5—*Mean hourly values of* $(r_H - r_{Hq})$ *in* γ *for all days at different years of a sunspot-cycle*

Hour, local time	1923	1924	1925	1926	1927	1928	1929	1930	1931	1932	1933	Mean 1923-1933	Mean[a] 1926-1929	Mean[b] 1923, 1924, 1932, 1933
h h														
00–01	3.8	4.3	5.1	6.7	6.3	6.1	6.4	9.4	6.4	7.2	6.1	6.2	6.4	5.3
01–02	3.6	4.5	4.9	7.6	5.1	5.8	5.6	8.3	5.6	6.9	5.8	5.8	6.0	5.2
02–03	3.7	3.7	4.3	6.7	5.1	4.6	5.6	7.1	5.2	6.4	5.0	5.2	5.5	4.7
03–04	3.1	3.1	4.3	5.7	4.4	4.2	4.5	6.6	4.5	5.7	4.7	4.6	4.7	4.1
04–05	2.8	2.9	3.4	5.0	4.0	4.5	4.3	5.6	3.9	4.7	4.5	4.1	4.5	3.7
05–06	2.8	3.4	3.7	4.8	3.8	5.2	4.7	5.6	4.3	4.1	3.8	4.2	4.6	3.5
06–07	3.5	4.1	5.2	5.8	4.6	6.1	6.1	6.2	4.6	4.7	3.7	5.0	5.7	4.0
07–08	5.0	5.5	5.5	6.8	5.4	6.6	6.7	7.0	4.9	4.9	4.5	5.7	6.4	5.0
08–09	5.6	5.9	5.3	6.3	5.5	7.5	5.8	5.1	4.9	5.8	4.7	5.7	6.3	5.1
09–10	5.8	6.5	6.5	7.9	8.6	7.7	6.4	7.7	5.9	5.4	5.1	6.7	7.7	5.7
10–11	5.8	6.9	5.6	7.3	8.1	8.0	9.3	8.8	6.3	5.6	5.0	7.0	8.2	5.8
11–12	6.1	6.1	7.7	7.9	7.9	8.4	9.3	9.8	7.4	6.9	5.7	7.6	8.3	6.2
12–13	6.1	6.1	8.4	7.2	8.2	8.3	8.7	10.7	8.2	6.7	7.3	7.8	8.1	6.5
13–14	4.8	5.3	6.1	7.1	8.1	8.3	7.2	9.1	6.4	6.6	6.9	6.9	7.7	5.9
14–15	4.7	4.5	5.8	6.1	6.0	8.3	7.2	8.3	6.1	6.9	6.9	6.4	6.9	5.7
15–16	4.9	4.4	6.0	6.2	6.9	7.8	7.3	9.8	6.5	7.1	7.5	6.8	7.1	6.0
16–17	5.5	6.0	6.1	6.9	8.0	7.1	7.7	9.9	6.6	6.4	6.9	7.0	7.4	6.2
17–18	4.9	5.0	6.4	7.3	7.7	7.5	7.5	10.2	6.6	7.1	6.8	7.0	7.5	5.9
18–19	3.4	4.8	6.0	7.2	6.8	6.5	7.2	8.7	6.0	6.5	6.2	6.3	6.9	5.2
19–20	3.2	4.2	4.8	6.8	6.1	6.5	7.2	9.6	7.0	6.7	6.1	6.2	6.7	5.1
20–21	4.2	3.4	5.5	7.3	6.5	7.6	7.6	9.7	6.1	6.6	6.4	6.5	7.2	5.1
21–22	4.2	4.0	4.9	7.9	6.2	6.0	6.5	10.1	6.0	7.4	6.8	6.4	6.7	5.6
22–23	4.4	5.0	5.1	8.0	6.5	6.5	7.3	10.4	6.6	7.6	6.5	6.7	7.1	5.9
23–24	4.0	4.3	5.0	7.0	6.6	6.3	7.1	9.9	6.3	8.1	6.3	6.5	6.7	5.7

[a]Sunspot-maximum. [b]Sunspot-minimum.

midday, a second at about 17^h, and a third at about 21^h. In summer, the late evening maximum is hardly evident. A little consideration will show that we should really think of the negative-departure disturbances as being made up of disturbances similar to the positive-departure ones, together with another kind having its maxima later in the day. These results, combined with the results of the present investigation regarding the diurnal variation of irregular disturbances, make it clear that there are two distinct agencies responsible for these disturbances, one being

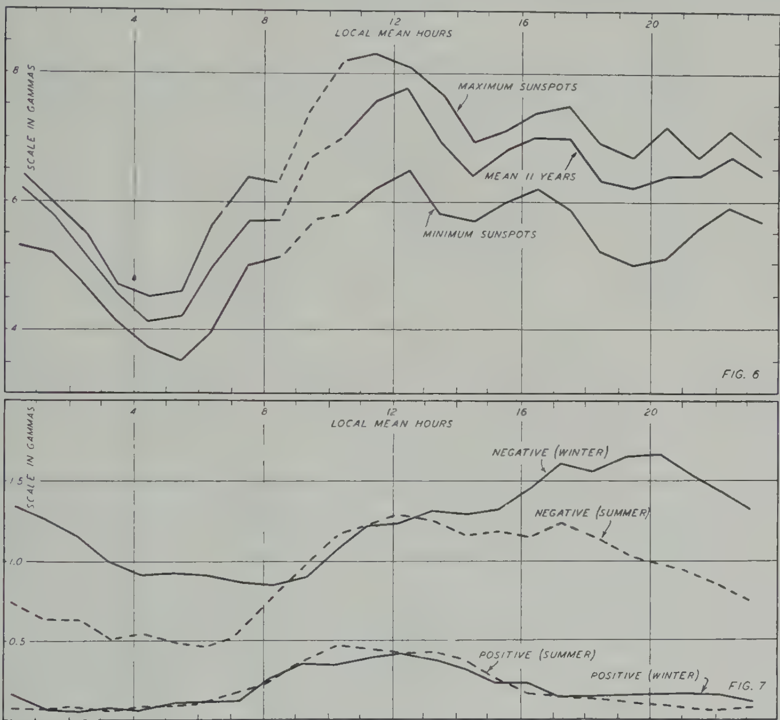

FIG. 6—DIURNAL VARIATION OF IRREGULAR DISTURBANCE OF H AT BOMBAY IN YEARS OF MAXIMUM AND MINIMUM SUNSPOTS, 1923-33

FIG. 7—AGGREGATES OF MAGNETIC DISTURBANCES AT BOMBAY WITH NEGATIVE AND POSITIVE DEPARTURES OF H IN SUMMER AND WINTER (1847-72, ACCORDING TO CHAMBERS)

responsible for the maximum at midday and the other for the late evening maximum. The former agency is probably variations in the ultraviolet light from the Sun which cause corresponding variations in the ion-content of the E- or F_1-layers of the ionosphere, while the latter is connected with disturbances of the magnetic-storm type.

Comparison of results of diurnal variation of disturbance with those obtained in other parts of the world—It is of interest to compare the diurnal variations of disturbance in temperate and polar latitudes with those at Bombay. For this purpose, we shall make use of the results of the investigations of Stagg [1]. Comparing Kew and Bombay, the following are the main points of difference. The index of disturbance at Kew was hourly character-figures (Fig. 8).

(1) At Kew, the time of minimum disturbance in the mean of the year is about 09^h local time and there is a marked advancement of the

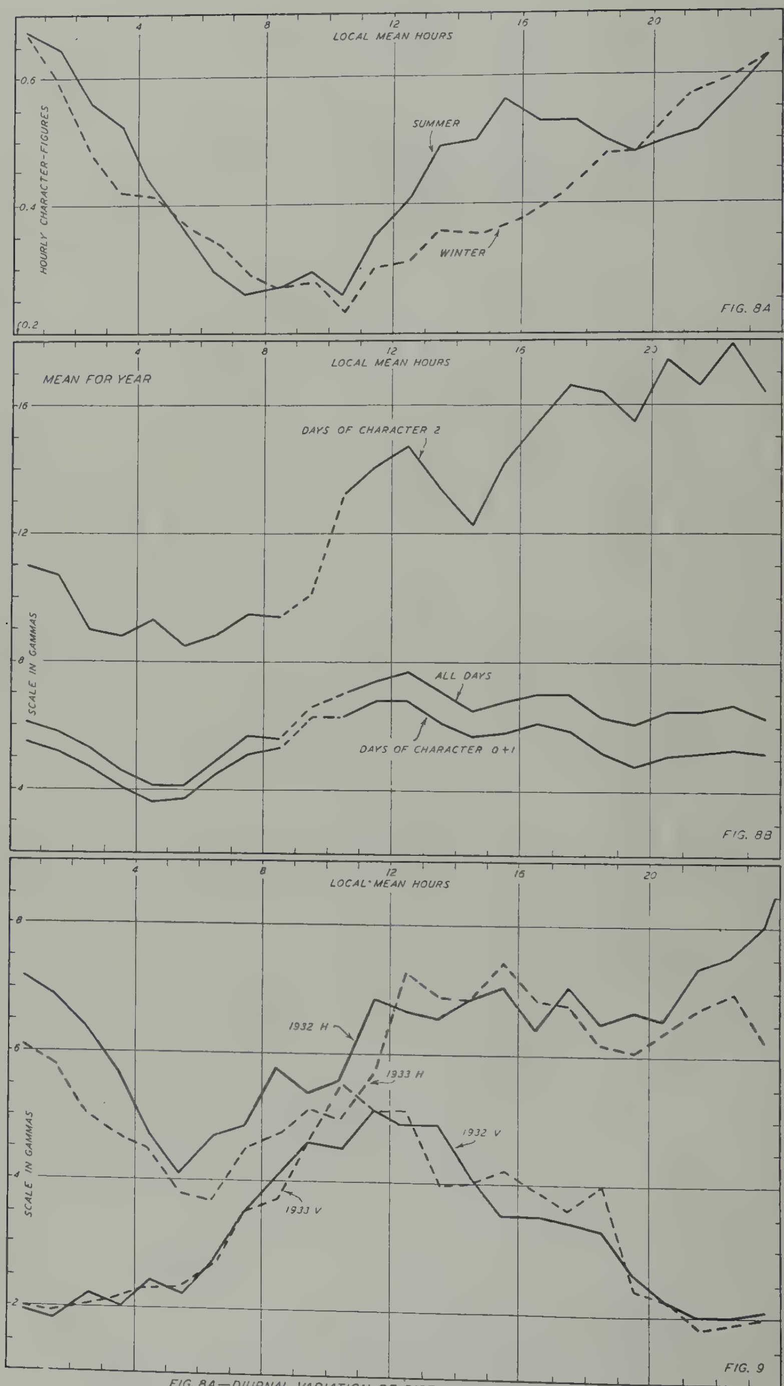

FIG. 8A—DIURNAL VARIATION OF DISTURBANCE OF H AT KEW
FIG. 8B—DIURNAL VARIATION OF IRREGULAR DISTURBANCE OF H AT BOMBAY
FIG. 9—DIURNAL VARIATION OF IRREGULAR DISTURBANCE OF H AND V AT BOMBAY

time of incidence of the minimum in going from summer to winter (from 08^h to $08^h\,30^m$ in summer to 10^h in winter). At Bombay the corresponding time of minimum disturbance is 05^h with a similar but less-marked advancement of time of incidence from summer to winter.

(2) At Kew, the principal maximum occurs between 00^h and 01^h local time. There is a seasonal development of a secondary maximum at about 16^h, this being most marked in summer. At Bombay, the principal maximum occurs at about noon and this is most pronounced in summer. There are two other maxima in the Bombay curves, one at about 17^h and the other at 20^h to 23^h. The latter is most pronounced in the winter.

(3) If we consider day of character 2 alone at Bombay, the pre-midnight maximum becomes much more pronounced and the curve of diurnal variation approaches the normal curve of variation at Kew.

In a later paper, Stagg [2] has collected together and analyzed the diurnal-variation data of a number of stations varying in magnetic latitude from 54°.5 north to 88° north. The disturbance-indices used at the different stations are not the same, some being functions of hourly ranges (Hr_H+Zr_Z) or Zr_Z alone (at high latitudes), some being hourly character-figures and some frequencies of disturbed hours. Stagg found that in the range of the latitudes mentioned above, the irregular disturbance-variation is controlled by local time. Comparing Eskdalemuir (latitude, ϕ, 55°.3 north, magnetic latitude, Φ, 58°.5 north), Sodankyla (Φ, 63°.8 north), and Fort Rae (Φ, 69°.0 north), Stagg found that the time of evening maximum of disturbance was $21^h\,30^m$ at Eskdalemuir, 23^h at Sodankyla, and 24^h at Fort Rae. Between 55° and 70° north magnetic latitude, there was thus a tendency for the time of maximum to be delayed with increasing Φ at approximately one hour for every 5° of latitude. At still higher latitudes than Fort Rae, for example at Godhaven (Φ, 79°.8 north), there is a conspicuous day-maximum at about 10^h, which is much more pronounced in summer than in winter.

Diurnal variation of disturbance of Z—The diurnal variation of irregular disturbance of Z was investigated in the same manner for the two years 1932 and 1933 and the mean yearly curves are shown in Figure 9. It is quite different in appearance from the curve of variation of H. The disturbance increases rapidly after sunrise and reaches a maximum at 10^h to 12^h and decreases in the afternoon, the afternoon fall being less rapid than the morning rise. There is just a suggestion of a pause in the rate of fall at about 17^h to 18^h.

As mentioned already, this difference in behavior between the diurnal variation of H and Z at Alibag is quite unlike their behavior in temperate latitudes where the irregular changes Hr_H and Zr_Z are similar.

Explanation of the variations—It is now generally accepted that the solar diurnal variations of the Earth's magnetic field are due to a system of electric currents in the upper atmosphere. It has been seen above that the daily variation of disturbance increases with the variation itself. It is therefore to be expected that the irregular disturbance-fluctuations of magnetic field are related to variations in the upper-air electric-current system. Now variations in the upper atmospheric-current system can vary either by a change in the conductivity of the upper atmosphere or by a change in the nature or intensity of the circulation. At present we can say but little about the latter, but we have some definite information about the former from ionospheric investigations.

It is now well-known that the ion-densities of the E-, F_1-, and F_2-regions of the ionosphere undergo more or less regular diurnal and annual variations. In the tropics, the variation of the ion-densities and heights of the ionospheric layers have been systematically investigated at Huancayo in Peru (12° south) by Berkner, Wells, and others [5]. The ion-density in the E-layer increases gradually after sunrise, reaches a maximum at about noon and again decreases in the afternoon, the morning and afternoon variations being nearly symmetrical. In the F_1-region, except in the early morning, the maximum ionization increases towards noon, becoming flat about noon, and decreases in the afternoon. As is well-known, the F-layer separates out into two layers F_1 and F_2 at about 08^h near the equator.

In the F_2-layer at Huancayo, the diurnal variation of ion-density is more complicated. There is a major maximum of ion-density in the morning at about 09^h local time, a minor maximum between 16^h and 18^h, and a secondary minimum at noon or slightly before noon. The afternoon maximum is least pronounced in the months June to August (in the Southern Hemisphere). At Watheroo (30° south) in summer the ion-density in F_2 increases after sunrise, reaches a maximum at about 14^h local time and decreases again in the evening; in winter, there are two maxima, one in the forenoon at about 11^h and the other in the afternoon at 15^h to 16^h. At Washington, the diurnal changes are generally similar to those at Watheroo—but in the months May to August, there is a tendency to approach the Huancayo characteristic of a late afternoon maximum.

It is reasonable to associate the maxima of disturbance-variation at Bombay at about noon and in the afternoon with the observed maxima of ion-density in low latitudes in the E- and F_1-layers and in F_2-layer, respectively. As regards the late evening maximum, it is presumably related to the deflection of electrified particles approaching the Earth from the Sun and their concentration on the side away from the Sun owing to the magnetic field of the Earth somewhat in the same manner as contemplated in the calculations of Störmer and demonstrated in the experiments of Birkeland. The effect of electrified particles will be greater in high latitudes than in low.

The above investigation was done under the direction of Dr. K. R. Ramanathan and I am grateful to him for his interest and encouragement. My thanks are also due to the Director General of Observatories at Poona, for permission to utilize the magnetic records collected by the India Meteorological Department.

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India Meteorological Department,
Poona, India, September 19, 1940.

NOTES ON ISOMAGNETIC CHARTS: V—THE OCCURRENCE OF LOCAL DIP-POLES

By S. Chapman

Summary—It is shown that local magnetic dip-poles occur in pairs or groups of pairs, and the nature of the isomagnetic lines and magnetic meridians is illustrated in the simpler cases. It is also shown that a local magnetic disturbance due to a single magnetic pole, if sufficiently intense, can produce one pair of dip-poles, and that if the disturbance is due to the field of a sufficiently intense local dipole, there may be either one or two local pole-pairs, according to the orientation of the dipole. If the dipole-field is due to magnetization induced in a roughly spherical mass of magnetite or iron pyrites, by the existing normal field, the necessary susceptibility of the mineral, if it is to produce local dip-poles, is shown to depend on the ratio of its radius to its depth, and on the local value of the normal horizontal intensity H. A classification of pole-pairs according to this value of H and the distance between the poles of a pole-pair is suggested.

§ 1. *Purpose*—In the preceding Note[1] of this series,[2] I considered various possible types of geomagnetic dip-pole (in this paper briefly called a *pole*). Two of these are called the *principal* (or *the*) magnetic poles: They are the points at which the magnetic potential V has its extreme surface-values; the point of maximum is called the south magnetic pole, and that of minimum is called the north magnetic pole. All other poles will be called *local.*

In this Note I consider the *occurrence* of local poles, and the form of the isomagnetic lines and magnetic meridians near pairs or groups of poles.

§ 2. *Summary of previously proved properties of poles*—In IV, § 5, it was shown that poles are singular points of the surface equipotential lines, and *vice versa*, and that there are two types of such singular points, namely, foci and nodes; consequently poles may be classified as *focal* or *nodal*, always with reference to the lines of equal potential.

A pole is a conical minimum focus of the horizontal-intensity (H) isomagnetic lines (IV, §§ 7, 9), a conical maximum focus of the isoclinic or dip (I) isomagnetic lines (IV, §§ 6, 9), and a ray-pole (in general non-uniform) of the declination (D) or isogonic lines (IV, § 10); in general it is an ordinary point on the total-intensity (F) and vertical-intensity (Z) isomagnetic lines (IV, § 8).

The character of the isomagnetic lines for H, I, D (and of course for F and Z) near a pole is the same whether this is focal or nodal, except that the variation of D round the pole is of opposite sign in the two cases (IV, § 10).

The magnetic meridians (IV, § 11) near a focal pole differ from those near a nodal pole. All the meridians near a focal pole either end or begin at the pole (according as V is a minimum or maximum); and they all touch one another there, except for two which approach the pole perpendicularly to the common tangent to all the others. Near a nodal pole two meridians reach the pole from opposite directions, and leave at right-angles to these directions; the adjacent meridians only skirt the pole.

§ 3. *Half the local poles are focal and half are nodal*—It was shown in II, § 4, that in any system of contour-lines whose singular points are all of simple character, the number of foci is two more than the number of nodes ($f=n+2$).

In the case of the system of equipotential lines, this implies that there are two more focal than nodal poles; since the two principal poles are

[1]Terr. Mag., **46**, 15-26 (1941).

[2]Terr. Mag., **45**, 433-442 and 443-450 (1940), **46**, 7-14 and 15-26 (1941); references to these Notes quote the numbers (I, II, III, and IV) of the Note and the paragraph.

focal, the remaining (*local*) poles must include equal numbers (N) of focal and nodal type. Hence the total number of local poles is even, $2N$.

In the case of the H isomagnetic lines, the theorem $f=(n+2)$ likewise signifies that the number N' of H-nodes is equal to the number of *local* H-foci, if we call local all the foci except the two which are the principal dip-poles. All the $2N$ local dip-poles are equal principal conical minimum foci of H; hence the number of H-foci which are not dip-poles is $(N'-2N)$.

§ 4. *The normal and the disturbing field*—In the study of the Earth's field it would be convenient in many ways to define a normal field approximating fairly closely to the actual field, but without sharing in its minor anomalies. The field that naturally received first consideration as a possible choice of normal field is that of the centered dipole, but for many purposes this does not give a sufficiently close approximation to the actual field, some of the anomalies being large and extensive.[3]

The field of an eccentric dipole is a natural second choice, and, as Bartels[4] has shown, it represents the actual field decidedly better than the centered dipole-field; but it still leaves important and extensive anomalies, which should be removed by a better choice of normal field.

The offices responsible for the production of world isomagnetic charts provide a practical solution of the problem of defining a normal field. Their charts are drawn on a scale too small to permit any indication of the finer details of the field-variations. These charts may be taken as defining a normal field for their epoch, by means of the isomagnetic lines actually drawn, and those which may be interpolated between them without serious ambiguity (except possibly near the nodes and foci, especially when the positions and chart-values there are not shown). In this Note the disturbing field will be defined as the difference between the actual field and this normal field. Symbols signifying the elements of the normal field will be distinguished by an accent (H', V', . . .), and the elements of the disturbing field will be denoted by the corresponding small letters (h, v, . . .).

The H'-isomagnetic lines, as shown, for example, on the British Admiralty 1922 charts [see also "Geomagnetism," p. 99] illustrate the theorem $f=(n+2)$, in that besides the two principal conical minimum foci, at the magnetic poles, there are two local ordinary foci (one at the principal maximum and the other at a secondary minimum) and two nodes (not shown).

§ 5. *Regions containing local poles*—The occurrence of a local dip-pole requires the existence of a disturbing field whose horizontal component h is at least as great as that (H') of the normal field in the locality. The larger the value of H', the more intense must be the disturbance h needed to produce a dip-pole; hence a local disturbing field of given intensity (less than the maximum value of H') will more readily produce a dip-pole, the nearer it is to one of the main poles, where H' is least.

But the existence of a disturbance of intensity h equal to or exceeding the local value of H' does not ensure the occurrence of a dip-pole; this involves the further condition that at one or more of the points at which $h=H'$, the two vectors $\mathbf{h}$ and $\mathbf{H}'$ shall be opposite in direction. Hence only some of the local disturbances which are sufficiently intense to produce poles will actually do so; in discussing the occurrence of dip-

[3] See Geomagnetism, by S. Chapman and J. Bartels, Oxford University Press, 1940, pp. 103-109.

[4] J. Bartels, Terr. Mag., **41**, 225, 1936; also see Geomagnetism, Oxford University Press, 1940, pp. 646-662.

poles, we are thus considering a doubly restricted class of H-disturbed region.

§ 6. *The simplest type of local disturbance in which dip-poles occur*—The simplest type of H-disturbance corresponds to the presence of a single H-focus and an associated H-node, in a region where in general the H-isomagnetic lines are roughly parallel and uniformly spaced (Fig. 1). According as the focus is a maximum or minimum, the node

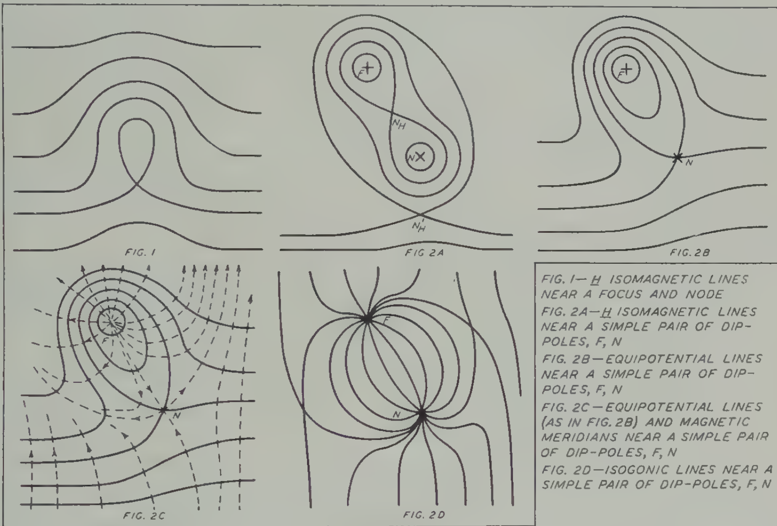


FIG. 1—$\underline{H}$ ISOMAGNETIC LINES NEAR A FOCUS AND NODE
FIG. 2A—$\underline{H}$ ISOMAGNETIC LINES NEAR A SIMPLE PAIR OF DIP-POLES, F, N
FIG. 2B—EQUIPOTENTIAL LINES NEAR A SIMPLE PAIR OF DIP-POLES, F, N
FIG. 2C—EQUIPOTENTIAL LINES (AS IN FIG. 2B) AND MAGNETIC MERIDIANS NEAR A SIMPLE PAIR OF DIP-POLES, F, N
FIG. 2D—ISOGONIC LINES NEAR A SIMPLE PAIR OF DIP-POLES, F, N

is the associated point of minimum descent or ascent (II, § 4). A maximum focus of H cannot be a dip-pole, and a minimum focus is in general not a dip-pole, because the minimum value of H will in general not be zero. A node of H cannot be a dip-pole because it is a stationary point with both smaller and larger values of H in its vicinity; whereas at a dip-pole H takes its least possible value, zero. Hence in general this, the simplest type of H-disturbance which is accompanied by singular points of the H-contours, does not involve the existence of a dip-pole; in other words, such ordinary singularities of H are not singularities of V.

A disturbance of the equipotential lines, similar to that of Figure 1, in an otherwise regular part of the V-contour system, corresponds to the presence of a V-node on one line, which is looped and encloses a V-focus; this disturbance does give rise to an associated pair of dip-poles, one focal (F) and one nodal (N).

Each of the two poles is also a special singularity of H (a conical minimum focus). The point of minimum ascent along the paths joining F and N must be a node N_H of H; the H-contour surface will rise above this node, in directions lateral to the path of minimum ascent; hence N_H may be considered as part of the general depression of the H-contour surface, whose extreme depressions are at N and F. This depression will, in the simplest case, be bounded by a loop of the H-isomagnetic lines, as in Figure 1, associated with another H node N'_H. Hence the simplest form of the H- and V-isomagnetic lines, associated with a V-disturbance of the type shown in Figure 1, is as shown in Figures

$2A$, $2B$: the H-nodes N_H, N'_H are not singularities of V. A pair of dip-poles for which the V-disturbance is of the type shown in Figure 1 or $2B$ may be called a simple pole-pair. The H-disturbance associated with a simple pole-pair cannot be less complex than Figure $2A$, but may be more so, having further foci (hills or depressions, the latter not descending to $H=0$), with a corresponding number of additional nodes. Thus the H-disturbance only partly corresponds to the V-disturbance.

As regards the common singularities of V and H, namely N and F, the principal axes of the H-isomagnetic lines there are the same as those for the V-lines: this is indicated by the crossed lines through N and F in Figures $2A$, $2B$: these crosses may or may not be parallel to one another.

§ 7. *The isomagnetic lines associated with a simple pole-pair*—The F- and Z-isomagnetic lines in the region of a simple pole-pair are in general ordinary; but they may have foci (hills and depressions, the latter not descending to zero), with a corresponding number of additional nodes, unassociated with N and F.

The isoclinic lines in the simplest case will be similar to the H-lines in Figure $2A$, except that F and N are absolute conical *maximum* foci of I, and the node corresponding to N_H is the lowest point of the path of minimum *descent* (on the I-surface) between N and F.

§ 8. *The magnetic meridians near a simple pole-pair*—The magnetic meridians, which outside the region of disturbance are nearly parallel, become greatly distorted near the dip-poles. The form of the magnetic meridians near either type of pole was described in IV, § 1; their general form in the whole region of a simple pole-pair is shown in Figure $2C$. (It is convenient to suppose that F is a maximum focus of V, so that all the magnetic meridians diverge from it; if F is a minimum focus all the arrows in Fig. $2C$ should be reversed.) The meridians are of course orthogonal to the equipotential lines. In the upper part of Figure $2C$ the meridians tend to parallelism, normal to the equipotential lines. The number of meridians leaving the Figure in its upper part exceeds the number entering at the lower part—this has no significance because the spacing of the meridians is arbitrary, without relation to the intensity of the field; the occurrence of a pole-pair in any region thus affects the spacing of the meridians in the undisturbed regions beyond, unless we arbitrarily refrain from continuing some of those used to indicate the non-uniformity of the direction of **H** near the poles.

§ 9. *The isogonic lines near a simple pole-pair*—The isogonic lines in the region of a simple pole-pair will next be considered. Immediately near each pole D takes all values from 0° to 360°; the direction of increase of D round the pole is opposite for N and F (IV, § 10). Let the range of declination D' for the *normal* field, over the disturbed region, be from θ_1 to θ_2 ($>\theta_1$), so that the isogonic lines for $D<\theta_1$ and $D>\theta_2$ pass on either side of the disturbed region, and are deflected only slightly if at all. Isogonic lines for such values of D, outside the range θ_1 to θ_2, are nevertheless present near each pole; they do not come from outside the disturbed region, and must therefore pass from one pole to the other; they may be called the *isolated* isogonic lines. They include the lines for most of the range of D from 0° to 360°, since the range $(\theta_1-\theta_2)$ will be small, unless the disturbed region is either very extensive, or lies near a pole of the axis of reference.

Between N and F, for example, where, apart from exceptional sinuosities, the magnetic meridians run opposite to the normal direction (Fig. 2C), D must be about 180° different from the normal value. The isolated isogonic lines must cover an area extending from N to F and on either side of the line NF. The boundary of this area is formed by transitional isogonic lines which come from outside the disturbed region, but nevertheless reach both the poles; each of these lines is nodal. The whole system of isogonic lines over the disturbed region is illustrated in Figure 2D, which represents the simplest possible case. We may note that the number of nodes is equal to the number of ray-poles, thus conforming to the equation $n=(f+r-2)$, which was mentioned in III, § 12 (at the end; see also the concluding passages in II §§ 7, 11) though not proved as a general theorem.

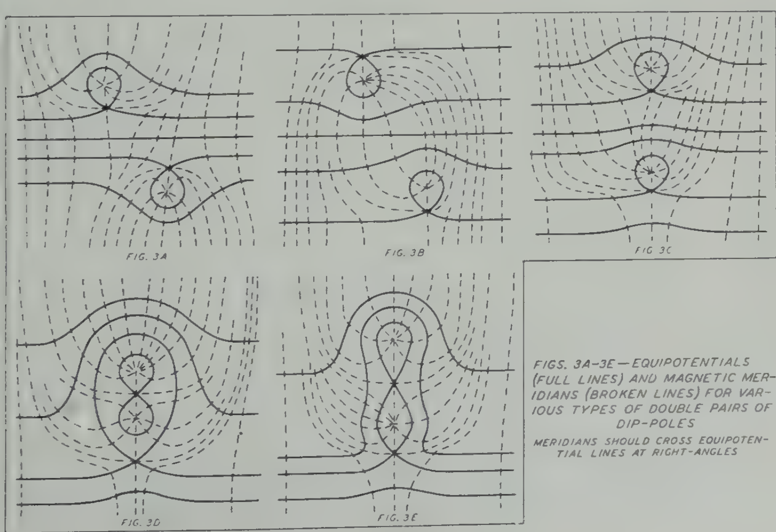
In Figure 2D the undisturbed direction of the isogonic lines has no necessary relation to the direction NF; it depends on the direction of the (geographical) axis of reference, and is therefore a "relative," not an "intrinsic," property of the field (I, § 5); a change in the direction of the axes of reference would alter the system of isogones almost everywhere; in particular, it would in general change the positions of the D-nodes in Figure 2D.

The isogonic system associated with a simple pole-pair cannot be less complex than as shown in Figure 2D, but may be more so, having additional foci and an equal number of additional nodes (but not additional ray-poles, which must be either dip-poles or poles of the axis of reference).

§ 10. *Double pole-pair disturbances*—After a simple pole-pair, the next least complicated disturbance including dip-poles will contain two nodal and two focal poles. This will be called a double pole-pair.

The nodal equipotential lines corresponding to a double pole-pair may have a variety of forms or dispositions, as illustrated in Figure 3.

In Figures 3A and 3B the focal poles are of opposite kind—one a maximum of V, the other a minimum; the magnetic meridians diverge



FIGS. 3A–3E—EQUIPOTENTIALS (FULL LINES) AND MAGNETIC MERIDIANS (BROKEN LINES) FOR VARIOUS TYPES OF DOUBLE PAIRS OF DIP-POLES

MERIDIANS SHOULD CROSS EQUIPOTENTIAL LINES AT RIGHT-ANGLES

from the former, and converge to the latter. In Figures 3C, 3D, and 3E the two foci are of like kind.

The disturbance of the smoothness of the magnetic meridians in the region of such double pole-pairs is shown in Figures 3A to 3E (broken lines). These are different combinations of the system of Figure 2C, embodying no essentially new feature. The disturbances in the other isomagnetic lines will not be illustrated.

§ 11. *Causes of local magnetic dip-poles*—So far we have considered the isomagnetic lines associated with different types of simple and double pole-pairs. We now consider some simple types of magnetic disturbance by which such pole-pairs may be produced, in an otherwise normal region of the Earth's surface-field.

§ 12. *A pole-pair due to the field of a local magnetic pole*—The simplest type of local disturbing field is that due to a long thin mass of magnetized matter, such that its field near either end approximates to the field of a simple magnetic pole, the field of the distant pole being negligibly weak there.

The surface equipotential lines due to such a field are circles centered at P, the surface-point vertically above the magnetic pole. The lines of the horizontal magnetic force of the disturbing field radiate from P (if the pole is a positive one). The disturbing horizontal intensity h increases from zero at P to a maximum h_0 at some radius r_0 from P, and then decreases to zero. If h_0 exceeds the local normal value H' of the horizontal intensity, there will be a simple pole-pair along the radius from P in the direction opposite to that of $\mathbf{H}'$. The equipotential lines and magnetic meridians will be as shown in Figure 2C. If the pole is negative the lines of force of the disturbing field converge to P, but similar considerations apply. The H-isomagnetic lines will be as illustrated in Figure 2A.

§ 13. *Dip-poles due to disturbance by a local magnetic dipole*—The next simplest local disturbing cause is a magnetic dipole, situated vertically beneath some surface-point P. In this case the occurrence of dip-poles depends greatly on the orientation as well as the depth d and moment m of the dipole. It is convenient to write $h_0 = m/d^3$, and to denote the horizontal distance of any surface-point from P by ρ.

If the dipole is vertical, its lines of surface-force are radial from P, as in § 12, though the variation of the disturbing potential v, and the disturbing intensity h, with the distance r from P are different. The maximum horizontal intensity of the dipole-surface field is $48h_0/25\sqrt{5}$ or $0.86h_0$; it occurs on the circle $\rho = d/2$. If $h_0 > H'/0.86 = 1.16H'$, there will be a dip-pole pair as in § 12, and Figures 2A, 2C will also apply (qualitatively) to the present case.

If the dipole is horizontal, let x- and y-axes be drawn horizontally through P, respectively opposite and perpendicular to the direction of the dipole. The potential v of the dipole at the surface-point x, y is given by

$$v = -my/r^3 \qquad r^2 = (d^2+\rho^2) = (d^2+x^2+y^2)$$

The x- and y-components of the surface dipole-field are given by

$$X_m = -3mxy/r^5 \qquad Y_m = m(d^2+x^2-2y^2)/r^5$$

The X_m-contours include the x- and y-axes, and the others are oval curves in the four quadrants, as shown in Figure 4A. The Y_m-contours

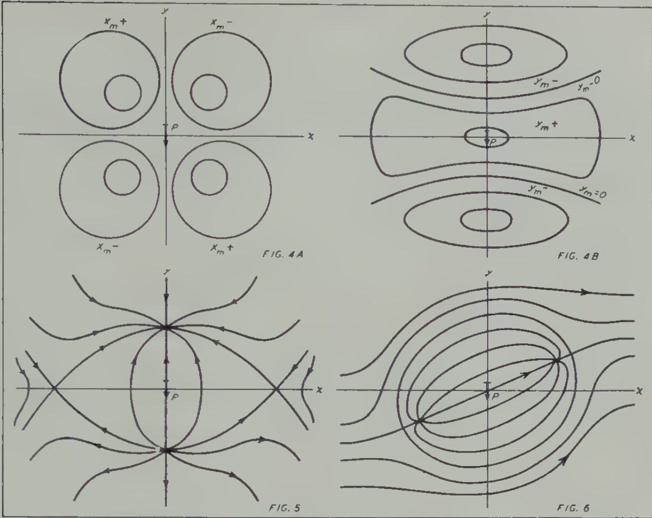


FIG. 4A—X ISOMAGNETIC LINES OF A HORIZONTAL MAGNETIC DIPOLE BELOW P (SCHEMATIC)
FIG. 4B—Y ISOMAGNETIC LINES OF A HORIZONTAL MAGNETIC DIPOLE BELOW P
FIG. 5—MAGNETIC MERIDIANS IN THE FIELD OF A LOCAL DISTURBANCE DUE TO A HORIZONTAL DIPOLE IN THE SAME DIRECTION AS THE NORMAL HORIZONTAL FIELD; $h_0>H'$
FIG. 6—MAGNETIC MERIDIANS IN THE FIELD OF A LOCAL DISTURBANCE DUE TO A HORIZONTAL DIPOLE AT RIGHT ANGLES TO THE NORMAL HORIZONTAL FIELD; $h_0>4H'$

are illustrated in Figure 4*B*; Y_m has a region of positive values between two regions of negative values, separated by the zero-contours $2y^2=(d^2+x^2)$; there are three stationary points, all foci; one is at P, where $Y_m=-h_0$, and the other two are at $x=0$, $y=\pm d\sqrt{(3/2)}$, where $Y_m=-Y'_0=-2(2/5)^{5/2}\,h_0=-0.202\,h_0$.

The X_m-contour system has one node, at the origin, and four foci, two positive and two negative, at $x=\pm y=\pm d/\sqrt{3}$; at these foci $X_m=\pm X_0$, where $X_0=(3/5)^{5/2}\,h_0=0.279\,h_0$. These foci lie in the region of positive Y_m.

Suppose that the normal field can be regarded as uniform over the region where the dipole-field is appreciable. Let X', Y' be the components of H' along the x- and y-axes, so that X', Y' here depend on the dipole-direction and are not the geographical components of the normal field; then $X=(X'+X_m)$, $Y=(Y'+Y_m)$. The stationary values of V are the points at which $(\partial V/\partial x)$ and $(\partial V/\partial y)$ are both zero, that is, the points common to the contours $X=0$, $Y=0$. The latter are the contours $X_m=-X'$, $Y_m=-Y'$. Hence the dip-poles are the points of intersection of these two contours, which (if they exist) are members of the families shown in Figures 4*A*, 4*B*.

These contours will not exist at all unless $X_0>|X'|$, and $h_0>Y'$ if Y' is negative, or $Y_0'>|Y'|$ if Y' is positive; the first condition is equivalent to $h_0>3.58\,|X'|$, and the third to $Y_0>4.95\,|Y'|$. These limits make greater or less demand on the intensity of the dipole-field, the greater or less the intensity of the normal field.

Even if the contours exist, they may not intersect. This may be illustrated by a few special cases.

Suppose that the dipole has the same direction as H', so that $X'=0$ and Y' is negative $(=-H')$. The contour $X=0$ in this case consists of

the x- and y-axes. If $h_0 > -Y'$, the contour $Y=0$ is a single closed curve, one of the Y_m-contours in the region of positive Y_m. This cuts the $(X=0)$-contour four times, twice on each axis, symmetrically with respect to P. The intersections on the y-axis are focal dip-poles, and those on the x-axis are nodal. The magnetic meridians are illustrated in Figure 5. In this case the dipole-field must satisfy the condition $h_0 > H'$. If, for example, $h_0 = (5/4)H'$, the two focal poles are at $y = \pm 0.22\ d$ approximately, and the two nodal poles are at $x = \pm 0.4\ d$.

If, however, the dipole has the direction opposite to H', so that $X'=0$ and Y' is positive $(=H')$, there will be no contour $Y=0$ unless $Y_0' > H'$ or $h_0 > 4.95\ H'$, a much more restrictive condition than in the preceding case. If this condition is satisfied, the contour $Y=0$ consists of two closed curves in the negative region of Y_m. These cut the contour $X=0$ at four points on the y-axis; the two inner points are foci, and the other two are nodes. The magnetic meridians are as in Figure 3B.

If the dipole is perpendicular to H', then $Y'=0$ and X' will be positive $(=H')$ if we take the positive sense of the x-axis to be in the direction of H'. The contour $Y=0$ is in this case the two-branched contour $Y_m=0$; the (numerical) maximum value of $\pm X_m$ along these lines is $(1/4)\ h_0$, at $x = \pm d/\sqrt{3}$, $y = \pm x\sqrt{2}$. Hence, unless $h_0 > 4H'$, the contour $X=0$ will not cut the contour $Y=0$. If $h_0 > 4H'$, there will be two pole-pairs, one on each branch of the line $Y_m=0$; the two nearer to P are foci, and the further two are nodes. The magnetic meridians are illustrated in Figure 6, which is only a distorted form of Figure 3B.

If the direction of H' agrees neither with that of the x- nor of the y-axis, there will likewise be two pole-pairs if Y_0 is sufficiently great; and the diagram of the magnetic meridians will be intermediate between Figures 3B and 6.

It remains to consider briefly the most general case of a local dipole-field, namely that of a dipole neither vertical nor horizontal (for definiteness let the upper pole be taken as the positive one). This case can conveniently be considered in relation to the magnetic meridians of the dipole-field itself. For a vertical dipole the meridians diverge radially from P; for a horizontal dipole they diverge from the point $x=0$, $y=-d\sqrt{2}$ and converge to the point $x=0$, $y=d/\sqrt{2}$. When the dipole is inclined upwards at the angle α (its horizontal component being in the $-y$-direction as before), the point of divergence approaches P, and that of convergence recedes from D. The contours $X_m=0$ are still rectilinear, namely $x=0$ and $(y-d\tan\alpha)$, and the other contours are ovals in the four quadrants thus formed; but the four extreme values are no longer equal—those at the X_m-foci nearer to P numerically exceed the other two. The contours $Y_m=0$ are now the curves $2y^2=(d^2+x^2+3yd\tan\alpha)$, and the whole Y_m-contour system is similar to that of Figure 4B, displaced in the positive direction of y, but so that the zero-contours lie on opposite sides of the x-axis. For a given value of the moment m and the depth d, as α increases from 0° to 90°, the maximum focus of Y_m moves along P_y in the positive direction, and the maximum value of Y_m at first increases so as to exceed h_0 slightly, and afterwards decreases again to $0.86\ h_0$; the minimum foci also move positively along O_y; the minimum value of Y_m at the focus on the positive side of P decreases to zero, and Y_m at the other minimum focus increases to the

limiting value, $48(h_0/25\sqrt{5})$ or $0.86\,h_0$, corresponding to the vertical dipole.

The dip-poles, as before, are the intersections of the curves $X_m = -X'$, $Y_m = -Y'$. The new feature is that the $(X=0)$-contour, if it exists, may have either one or two branches, whereas when $\alpha=0$ it has two (or none). Hence there may be either one or two (or no) pole-pairs. When there are two pole-pairs, the magnetic meridians have the same general shape as before, and when there is only one pole-pair, the diagram of meridians is merely a slightly distorted form of Figure 2*A* (dotted lines).

§ 14. *Dip-poles due to local disturbance by a magnetized sphere*—The field of a sphere of radius a uniformly magnetized with intensity **I** is the same, at external points, as that of a dipole of moment $(4/3)\pi a^3\,\mathbf{I}$ $(=\mathbf{m})$, situated at the center O of the sphere. Hence the discussion of § 13 applies to the disturbance produced by such a sphere. The disturbance is most intense if the sphere is just buried, that is, if $d=a$, where d, as before, denotes the depth of the equivalent dipole. In this case $h_0 = m/d^3 = (4/3)\pi I$. We have seen in § 13 that such a local disturbance can produce either one or two pole-pairs (not more), if h_0 is of the same order of magnitude as the local normal horizontal intensity H'; the necessary ratio (h_0/H') varies from slightly less than 1 (when **I** is only slightly inclined to **H**$'$, and in the same vertical plane) to nearly 5, according to the orientation of **I** or **m**. The corresponding range of (I/H') is approximately from 1/4 to 1.

If the material of the sphere is of susceptibility κ, and its magnetization is induced by the existing (normal) field F', (I/H') will be $(\kappa F'/H')$ or $(\kappa \sec i)$, where i denotes the inclination or dip. In this case $(\kappa \sec i)$ must lie within the range 1/4 to 1 (approximately); the nearer the poles, and therefore the greater the value of i, the less restrictive is this requirement regarding κ. Moreover the fact that the horizontal component of **m** has the same direction as **H**$'$ is favorable to the production of two pole-pairs, as in Figure 5, for values of $(\kappa \sec i)$ down to the lower limit 1/4.

For magnetite κ lies between 0.1 and 30, and for magnetic pyrites it may be as large as 0.4 [see "Geomagnetism," p. 144]; for most other natural minerals it is much less. It is clear that a sphere of magnetite or iron pyrites of whatever radius, provided it is just below the surface, can readily produce one or two pairs of dip-poles, provided that $\kappa' > (1/4)$ if the sphere is at or near the equator, or for lower values of κ' in higher latitudes; in high latitudes where **F** and **m** are nearly vertical, one and not two pole-pairs will be produced, as in Figure 2.

If, however, the spehere is more deeply buried, the requirement $(1/4) < (\kappa \sec i) < 1$ is changed to $(1/4) < \kappa (a/d)^3 \sec i < 1$, which necessitates a value of κ, other things being equal, $(d/a)^3$ times as great as for a sphere just below the surface.

§ 15. *The occurrence of natural dip-poles*—Any natural magnetizable mineral-deposit, in a form not too elongated in any direction, will have a field roughly resembling that of a sphere of similar size, so that if its susceptibility satisfies the inequalities of § 14 it will produce one or two pole-pairs. As the requirement regarding κ' is not unduly restrictive, for deposits of magnetite or pyrites which come up to the surface or

form outcrops, it is to be expected that pairs of dip-poles are not particularly rare, especially in higher latitudes. In the case of elongated deposits like those at Kursk and Kiirunavaara, the conditions will be less simple, but the presence of at least one pole-pair, and probably of many, is to be expected there.

The question as to how many local pairs of dip-poles exist on the Earth has probably no ascertainable answer, because even a pebble of magnetite or pyrites could produce one or two pairs, especially in high latitudes. To render the question answerable it is necessary to classify local pole-pairs according to their importance, which demands some basis of classification for them. It seems natural to take as one element in the classification the distance d' between the poles of a pair, or the mean distance d' between the poles of a group where two or more pairs fall in an isolated region surrounded by a normal region. This distance, in the special cases considered in §§ 13, 14, is of order d, the depth of the equivalent dipole; if the disturbing field is only barely sufficient to produce dip-poles, (d'/d) will indeed be rather small.

It seems natural also to make the classification depend on the normal value of H' in the locality, requiring a greater value of d' where H' is weak (so that a weak disturbing field can produce dip-poles) than where H' is strong. Hence it is suggested that pairs or groups of dip-poles should be classified according to the value of $d'H'$, and that only those for which $d'H'$ is of order 1 km-gauss should be regarded as significant. This would require that at the equator, where H' is about 1/3 gauss, the weakest "significant" pole-pair would have an inter-polar distance of 3 km, or 2 miles; such a disturbance could be produced by a just-buried desposit of similar radius, if κ is of order 1/4, or by a smaller deposit of higher susceptibility. Where $H'=0.1$, a threefold larger or more susceptible deposit is necessary. It would be interesting to know how many "significant" pairs or groups of local dip-poles there are, according to this criterion.

§ 16. *Changes in the positions of dip-poles*—Finally it may be noted that, owing to the secular variation of the Earth's field, local dip-poles must slowly change their positions, but that, if they are due to local deposits magnetized either permanently or by induction, they must always be restricted to a region of linear dimensions of order d; the secular variation may cause pole-pairs to disappear or new ones to appear.

The daily geomagnetic variation will also cause a daily variation in the position of dip-poles, and magnetic disturbance will produce irregular displacements. These will however in general be very small. They are likely to be greatest for the principal magnetic poles where the horizontal gradients of H are much smaller than near local poles; if the local gradients are taken to be the same as if the principal poles coincided with the axis-poles (thus ignoring the local irregularities in the region), we have $(\partial H/\partial\theta)=H_0 \cos\theta=H_0$, where θ denotes the magnetic colatitude (which is zero at the axis-pole), and $H_0=0.34$, the equatorial value of H. Hence the horizontal gradient of H, $(\partial H/a\partial\theta)$, is (H_0/a); if the range of H in the daily geomagnetic variation (in this region mainly due to S_D) is taken to be 100γ, the corresponding range in the position of the dip-pole will be $100\ \gamma a/H_0$ or $a/340=20$ km approximately.

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MAGNETIC HORIZONTAL INTENSITY AT OSLO, 1843-1930

By K. F. Wasserfall

Oslo Magnetic Observatory

The Oslo Magnetic Observatory was founded by Professor Christopher Hansteen. The geographical coordinates of the station are $\phi = 59° 54'.7$ north, $\lambda = 10° 43'.4$ east.

The results published in this paper are based on magnetic data left by Hansteen and on the work done by his successors. The large bifilar magnet was mounted in May, 1841. This magnet is 1.2 meters long and weighs 13 kg. The suspension, which is nine meters long with 35 mm between the two threads, is solidly fixed to the vault of the central hall of the building. The two-story hall has a gallery on the

FIG. 1—LARGE HORIZONTAL-INTENSITY MAGNET SUSPENDED FROM VAULT OF CENTRAL HALL OF OBSERVATORY

second floor—the vault carrying the astronomical equatorial tower of the building.

The magnet is free to oscillate inside a wooden box, which rests on four legs 30 cm high. The glass cover of this box has an opening in the middle through which the mirror and the brass cylinder may be passed and mounted on the suspension. Two Réaumur thermometers are placed inside the box, above the poles of the magnet. As further protection a wooden barrier was built around the box in 1872 (see Fig. 1).

The eye-readings for observations are made by means of a telescope mounted on a marble pier in the west wing of the building. To the pier, near the wooden floor of the room, is fixed a large scale graduated into two-mm divisions. The distance between the scale and the mirror is 985.0 cm. As a fixed mark of reference for the readings, a plumb-line is fixed to the pier and is suspended immediately in front of the scale so that the vertical plane through the line, perpendicular to the scale, coincides with the optical axis of the telescope. This arrangement is shown in Figure 2.

The regular readings of the variometer began January 1, 1843. Two observations were taken daily—one at 09^h, and one at 14^h, local mean time. These observations have been continued to the present. When standard time was introduced in Norway in 1894, the observations were still taken on local mean time which is equivalent to $09^h\ 10^m$ and $14^h\ 10^m$, middle European time (MET).

FIG. 2—PIER WITH TELESCOPE USED FOR EYE-READINGS OF VARIATION-MAGNET (SCALE FIXED TO LOWER PART OF PIER; PLUMB-LINE APPEARS IN FRONT OF SCALE)

Each observation consists of ten single readings on the scale and these are entered in a note-book as shown in Table 1 which gives the morning observation of June 3, 1863. The mean value of the readings is seen to be 670.7 pars at a temperature of 8°.7 R.

The mean time-interval between the readings of the first and second columns is 72 seconds, which corresponds to the average time-interval required for a single oscillation of the magnet. The time-interval between the readings in each column is ten seconds, so that a complete observation requires about two minutes.

TABLE 1

Eye-readings		Mean
pars	*pars*	*pars*
673.0	668.8	670.90
673.3	668.2	670.75
673.0	668.3	670.65
672.4	669.0	670.70
671.6	669.8	670.70
Mean		670.74
Mean temp.		8°.7 R

After the magnet was mounted in May, 1841, nothing was altered until August, 1876, when the thread was broken by accident—a mason, who was repairing the vault, hit the thread with a heavy wooden beam, causing the magnet to fall. Shortly afterwards the magnet was remounted but regular readings were not resumed until February, 1878. The readings during the first years after the accident show that the suspension required a very long time to settle down—in fact the base-line value did not become steady (more or less constant) until after 1890 (see Fig. 13*A*).

MEASUREMENT FOR DETERMINATION OF THE CONSTANTS

Scale-value—Only two observations have been made for direct determination of the scale-value. The first was made by Hansteen in April, 1842, and the second by Fearnley in January, 1878. The observations and the determinations of the scale-value were made according to a method described by Gauss.[1] As the variometer at the Oslo Observatory is of a type no longer used, the following theoretical remarks may be of interest.

Suppose the magnet to rest in the magnetic meridian and that the suspension is torsionless in this position. If the torsion-head is turned through the angle z, the magnet forms an angle ϕ with the meridian, determined by the equation

$$MH \sin \phi = D \sin (z-\phi) \tag{1}$$

If $\phi=90°$ and $(z-90°)=\psi$, we have

$$MH = D \sin \psi \tag{2}$$

A magnet suspended in this position was said by Gauss to be in a "transverse" position and for the torsional moment D, if we disregard the torsion of the individual threads, we have

$$D = P\ \delta_1\delta_2/4l \tag{3}$$

where P is the weight of the whole system, l is the length of the suspension, and δ_1 and δ_2 are the distances between the two threads at the bottom and top, respectively. As in the transverse position a change in declina-

[1]C. F. Gauss and W. Weber, Resultate aus den Beobachtungen der Magnetischen Vereins 1837 und 1840; J. Liznar, Anleitung zur Messung und Beobachtung der Elemente des Erdmagnetismus, Wien (1883).

tion has no influence on the position of the magnet, a change of H can be directly measured by the corresponding change in the angle ψ. By logarithmic differentiation of equation (2), considering M and D constants, we get

$$(dH/H) = \cot \psi \, d\psi \tag{4}$$

If, therefore, we let ϵ denote the value of dH, corresponding to one scale-unit, ϵ being the angular value of one scale-unit expressed in minutes of arc, we have

$$H (\cot \psi) \ \epsilon \sin 1' = \epsilon_h \tag{5}$$

Determination of the scale-value by direct observation of the angle ψ is sufficiently exact only if there is a correspondingly fine division attached to the torsion-head, but as this is not the case with our instrument, the angle ψ is determined indirectly by observing one oscillation with the suspended magnet, first placed "direct" with the north pole pointing towards the north and second placed "inverted" with the north pole pointing towards the south—this being possible, if the torsional moment is so large that D is greater than MH.

Disregarding the effect of magnetic induction, as well as the torsional effect of the individual threads, and assuming the moment of inertia to be the same in both cases, we have

$$T_1 = \pi\sqrt{K/(D+MH)} \text{ and } T_2 = \pi\sqrt{K/(D-MH)} \tag{6}$$

where K is the moment of inertia. Referring now to equation (2) we get

$$\sin \psi = (T_2^2 - T_1^2)/(T_1^2 + T_2^2) \tag{7}$$

The time of one oscillation is of course supposed to be corrected so that it refers to an infinitely small arc and the normal value of H at 0° R. If we also observe the time of one oscillation with the magnet in the transverse position, we should get a valuable control. For this position we have

$$T_3 = \pi\sqrt{K/D \cos \psi} \tag{8}$$

and between T_1, T_2, and T_3 there exists the relation

$$T_3 = \sqrt{T_1 T_2} \tag{9}$$

The three quantities T_1, T_2, and T_3 were observed by Hansteen and Fearnley and the results obtained by them are given in Table 2. We do not know the exact value obtained by Hansteen for the quantity T_3 as it cannot be found in the old documents. This, however, is of no

TABLE 2

Position	April, 1842		January, 1878	
	Oscillation	Temperature	Oscillation	Temperature
	sec	° R	*sec*	° R
T_1	38.50	7.4	38.76	1.8
T_2	128.07	7.4	152.81	0.5
T_3	ca. 72	...	72.04	2.6

great consequence since the value cannot differ greatly from 72 seconds mentioned above as the average time of one oscillation.

From the values observed from T_1 and T_2 Hansteen and Fearnley computed the scale-value ϵ_h, obtaining the following results[2]: Hansteen's value for 1842, $\epsilon_h = H/15970$; Fearnley's value for 1878, $\epsilon_h = H/15914$. Using the approximate values $H = 15{,}500$ for 1842 and 16,000 for 1878, we obtain $\epsilon_h = 0.971$ per scale-division for 1842, and $\epsilon_h = 1.005$ per scale-division for 1878. If, now, we insert the above values for T_3 in the control-equation (9), it is found that a satisfactory agreement is not obtained. It proved impossible to control the above-given data for ϵ_h, since sufficient details are not found in the old documents; on the other hand, there is reason to believe that the disagreement found by using the control-equation is mainly due to the fact that the torsion of the individual threads has been neglected. As the suspension consists of a double thread, it is very probable that the torsional effect of the threads is considerable.[3]

In the old documents we note that Professor Geelmuyden made a series of calculations to settle the question regarding the torsional effect of the individual threads. His research, however, did not lead to any conclusive results. As far as can be ascertained, neither Hansteen nor Fearnley took this effect into consideration,[3a] and hence we conclude that the control-observation T_3 was not employed. It is, nevertheless, of interest to learn what effect may be ascribed to an individual torsion of the threads.

Considering the combined torsional effect of the unifilar- and the bifilar-suspension, we may write

$$\epsilon_h = [D_1 \cos \psi D_2/(D_1 \sin \psi + D_2 \psi)] H (1.015 \times 10^{-4}) \qquad (10)$$

and try to arrive at an expression for the ψ-function in ϵ_h by using the times of oscillation T_1, T_2, and T_3. Since the induction-factor may be disregarded, we may in the direct and in the inverted position make $D = (D_1 + D_2)$ in equation (6) and for the transverse position we may write

$$T_3 = \pi \sqrt{K/(D_1 \cos \psi + D_2)} \qquad (11)$$

whence

$$\epsilon_h = [2T_1^2 T_2^2/(T_2^2 - T_1^2) T_3^2] H (1.015 \times 10^{-4})\ \gamma \text{ per division} \qquad (12)$$

The correct value for ϵ_h should thus be found by introducing the three observed values of time of oscillation into this equation after reducing the observations to constant temperature and constant H. As, however, Hansteen's value for T_3 is only approximate, and as the variations in temperature and in H are very small in Fearnley's case, we may disregard these corrections and use the values given in Table 2 directly. Furthermore, the approximate values $15{,}500\gamma$ and $16{,}000\gamma$, for 1842 and 1878, respectively, may be used. The scale-values are then $\epsilon_h = 0.989$ per scale-division for 1842, and $\epsilon_h = 1.005$ per scale-division for 1878. This shows that the value for 1842 is close to that obtained directly from Hansteen's data given above, while the value for 1878 is the same.

[2]H. Geelmuyden, Magnetische Beobachtungen, Kristiania (1891).

[3]H. Wild, St. Petersburg, Bull. Ac. Sc., **26**, 76 (1880).

[3a]See p. V of reference 2.

The temperature-coefficient—The temperature-coefficient for the bifilar magnet was determined by observations made by Hansteen in April, 1841, following a method described in detail by him. The determination of the temperature-coefficient was repeated on three occasions and the readings of the position of a unifilar magnet with corresponding temperature-readings covered the range from 0° to 25° R. Special precautions were taken to prevent change in the magnetic moment during the experiment. Hansteen gives the following equation and values

$$H_0 = H + \alpha(t-t_0) + \beta(t-t_0)^2 \tag{13}$$

where $\alpha = 12.305 \times 10^{-5}$, $\beta = 0.124 \times 10^{-5}$, and $t_0 = 5°.0$ R.

Using these constants Hansteen reduced some of his bifilar readings in order to compare them with his absolute observations and there is no reason to doubt them. Therefore Hansteen's value has been used in our reductions, but as he completely disregarded a possible temperature-influence of the suspension, it was necessary to examine this problem. The numerical values for the angle ψ and the ratio $(D_2\ D_1)$ can be obtained with the aid of Fearnley's data for T_1, T_2, and T_3 (Table 2). Thus we get $\psi = 59°.8$ and $(D_2/D_1) = 0.08973$. The torsion of the individual threads should thus be about nine per cent of that of the bifilar suspension. By aid of this we may estimate the effect of the temperature-variation.

The expression for D_1 is given by equation (3), where the temperature-coefficients δ_1 and δ_2, expressed in the Réaumur scale, are the dilatation-coefficient of brass ($\beta_b = 0.000023$) and the corresponding coefficient for l is that of steel ($\beta_s = 0.000015$). The temperature-coefficient for D_1 will thus be $(2\beta_b - \beta_s) = 0.000030$, or $D_1 = \mathrm{D}_0\ (1 + 0.000030\ t)$. According to Wild[3]

$$D_2 = 2\pi\rho^4 \epsilon/\sigma l \tag{14}$$

where ρ is the radius, ϵ is the coefficient of elasticity, and l is the length of the threads. We may thus write

$$\rho = \rho_0(t + \beta_s t) \qquad \epsilon = \epsilon_0(-\beta_e t) \qquad l = l_0(1 + \beta_s t)$$

where for β_e we put 0.00025. Introducing these values

$$D_2 = D_{2_0}(1 + 3\beta_s t - \beta_e t) = D_{2_0}(1 - 0.00021\ t) \tag{15}$$

hence $(D_2/D_1) = (D_{2_0}/D_{1_0})(1 - 0.00021\ t)$.

Hansteen determined the effect of the temperature on the magnet, as above stated, but, as the original observations are not available, the result is stated as given in Geelmuyden's paper; this may probably be assumed to be in agreement with the original result in the old documents left by Hansteen. Geelmuyden gives

$$B = b + 12.26(t - 5°) + 0.124(t - 5°)^2 \tag{16}$$

where B and b are scale-readings. As the scale-value is nearly 1γ per pars, this equation will be practically the same as

$$H = H_0 + 12.3\ t \times 10^{-5} \tag{17}$$

where H and H_0 are expressed in γ. Since H may be put approximately at $16{,}000\gamma$

$$H=H_0(1+0.00077\ t) \tag{18}$$

and for the equilibrium we have

$$MH=D_1 \sin \psi+D_2\psi \tag{19}$$

When the temperature changes there will be a temperature-variation in the magnet-housing and this variation may be read on the thermometer fastened to the inside glass cover. The suspension will be influenced by the temperature of the air in the room outside the housing (the bifilar and the unifilar constants, D_1 and D_2) in different ways. The temperature-variation in the room will be much greater than that of the magnet. No temperature-readings were taken in the room itself. According to the above statement, it was assumed that the three temperature-readings t_0, t_1, and t_2, affected the magnet, D_1, and D_2, respectively, as follows

$$\left.\begin{aligned} \mathrm{d}M&=M(0.00077)\mathrm{d}t_0 \\ \mathrm{d}D_1&=D_1(0.00003)\mathrm{d}t_1 \\ \mathrm{d}D_2&=D_2(0.00020)\mathrm{d}t_2 \end{aligned}\right\} \tag{20}$$

Using the values for ψ and (D_2/D_1), and introducing the above numerical values for $\mathrm{d}M$, $\mathrm{d}D_1$, and $\mathrm{d}D_2$, we obtain

$$\mathrm{d}\psi=-0.001244\ \mathrm{d}t_0-0.000035\ \mathrm{d}t_1+0.000025\ \mathrm{d}t_2 \tag{21}$$

Since $\mathrm{d}\psi=0.0001015\ \mathrm{d}B$ and the correction must be taken with opposite sign, we may write the correction in the scale-readings caused by the temperature-variation in the form

$$12.3\ \mathrm{d}t_0+0.33\ \mathrm{d}t_1-0.25\ \mathrm{d}t_2 \tag{22}$$

The first term, which depends on the variation of the moment of the magnet, is the predominant one, but the variation in t_0 is much less than that in t_1 and t_2. The latter may often be ten times greater, especially as D_1 for the dominant part is influenced by the temperature close under the roof. There is therefore every reason to believe that the temperature-effect of the suspension may be so great that it should be taken into account. As, however, no room-temperatures are available, this effect can only be determined from the magnetic data.

Determination of the constants by means of absolute measurements

General remarks—As no special observations suitable for the determination of the temperature-coefficient for the suspension, λ, have been made, and as there may be some uncertainty regarding the constance of the scale-value, ϵ_h, since we have only the two observations of 1842 and 1878, we have attempted some control-determinations for the two constants by means of direct comparison between relative and absolute data.

The principal difficulty was the often unknown abrupt changes in the relation between scale and mirror, "the base-line value," in addition to the unknown interplay of the effects of the two insufficiently de-

termined constants λ and ϵ_h. The procedure, therefore, consisted of a series of approximations, whereby we could start with a constant value for ϵ_h, for instance, 1 pars $= 1\gamma$. As to the absolute data, the main difficulty lies in the uneven distribution, plainly seen in Tables *A* and *B*. From Table *C* one may also get a good idea of the difficulties connected with the numerous abrupt changes in the base-line values.

The temperature-coefficient for the suspension—We define the temperature-coefficient of the suspension, λ, by the equation

$$H_0 = H_1[1+\lambda(t-t_0)] \tag{23}$$

where H_0 is the observed value, reduced to standard temperature both for the magnet and for the suspension, while H_1 is the observed value, reduced only to standard temperature for the magnet. The method for extracting the value for λ will be understood from the following example given in Table 3 and in Figure 3. During 1844-55 no abrupt changes in the base-line value appear to have occurred and in the data for temperature there is a range of about 18° R. Therefore, a good expression for the temperature-influence should be possible. In Table 3 the eye-readings

TABLE 3

Year	Date	h'	ϵ_h	h'	t	c_a	h	H'	B'_h
		p	γ	γ	° R	γ	γ	*cgs*	*cgs*
1844	May 21	469	0.995	467	+ 9.1	+ 52	519	0.15537	0.15018
	21	472	0.995	470	+ 9.4	+ 56	526	0.15547	0.15021
1845	May 21	488	0.998	487	+ 8.6	+ 46	533	0.15557	0.15024
	21	490	0.998	489	+ 8.8	+ 48	537	0.15561	0.15024
	22	459	0.998	458	+ 8.1	+ 40	498	0.15510	0.15012
	Nov. 15	549	0.999	548	+ 3.4	− 19	529	0.15529	0.15000
1846	Jan. 31	624	1.000	524	− 2.7	− 88	536	0.15485	0.14949
	31	625	1.000	625	− 2.7	− 88	537	0.15489	0.14952
1848	May 27	599	1.005	602	+ 9.9	+ 63	665	0.15680	0.15015
1850	Apr. 20	527	1.010	532	+ 8.3	+ 42	574	0.15575	0.15001
	20	530	1.010	535	+ 8.3	+ 42	577	0.15576	0.14949
1851	June 24	440	1.011	445	+15.1	+137	582	0.15611	0.15029
	July 18	519	1.011	525	+11.7	+ 88	613	0.15641	0.15028
	Sep. 4	530	1.011	536	+12.4	+ 98	634	0.15651	0.15017

are multiplied by the final scale-value, ϵ_h, and thus expressed in γ. Under the heading H' we have entered corresponding values for horizontal intensity according to Hansteen's observations of oscillation, reduced to absolute values by use of the constants fixed by him—for instance, the logarithmic temperature-coefficient for Dollond's cylinder $b_s = 14.9$. H and the eye-reading, h, are related to the base-line value, B_h, through the formula

$$B_h = (H-h) \tag{24}$$

In Figure 3 the average line through the points has been so drawn that $\lambda = 5.4\gamma$ per 1°.0 R; this value refers to the first month of 1848. Several other tests gave values for λ, which averaged about the same as shown in Figure 3. Comparing this result with the conclusion drawn above, it appears that the influence of temperature on the suspension

is considerably larger than one should expect. It must be remembered, however, that the temperature-reading used is correct only when it concerns the magnet and that the temperature, on which the correction in reference to the suspension depends, is that of the free air of the room and especially of the air near the roof which will be considerably higher than the reading given in Table 3 to obtain the value of λ. This fact explains, at least to a certain degree, the high values of Figure 3.

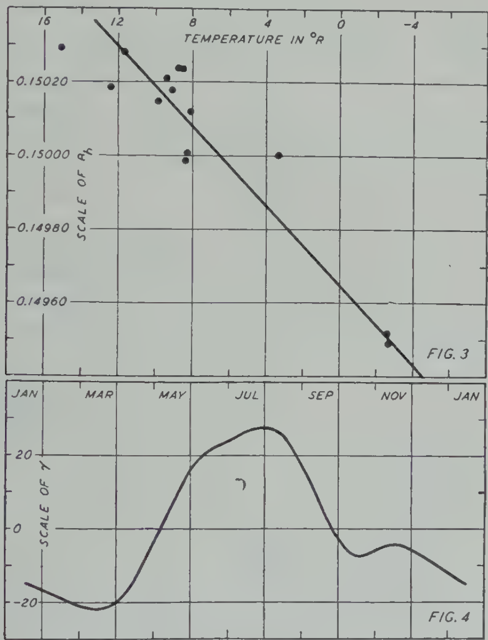


FIG. 3—INFLUENCE OF TEMPERATURE ON SUSPENSION, MAY 21, 1844 TO SEPTEMBER 4, 1851 (VALUE b_s=14.9 USED FOR REDUCTION OF H')

FIG. 4—MEAN ANNUAL WAVE IN H CORRECTED FOR NON-CYCLIC CHANGE 1843-53 (REDUCTION DEPENDS ON b_s=14.9, FOR LOGARITHMIC TEMPERATURE-COEFFICIENT OF DOLLOND'S CYLINDER)

However this may be, there seems to be no doubt that a λ-correction must be introduced in the formula for reducing the eye-readings. The complete formula, therefore, assumes the form

$$h_0 = h + (\alpha + \lambda)(t - t_0) + \beta(t - t_0)^2 \tag{25}$$

where α and β represent the two coefficients found by Hansteen for the magnet, and λ represents the temperature-coefficient of the suspension.

As there was no reason to doubt the correctness of the result obtained for λ, according to Figure 3 and the other tests mentioned above, a reduction of the eye-readings was started using the coefficients given above for the temperature and data for the scale-value ϵ_h fixed by Hansteen's and Fearnley's observations and controlled as indicated later. The results so compiled seemed more or less satisfactory and a large

series was reduced. The data obtained daily for H at 09^h were now arranged in tables; the monthly and annual mean values of these are given in Table D. From the mean monthly values for the entire 11-year

TABLE 4

Month	H	Month	H	Month	H
	γ		γ		γ
Jan.	−15	May	+ 7	Sep.	+6
Feb.	−19	June	+22	Oct.	−8
Mar.	−22	July	+26	Nov.	−6
Apr.	−15	Aug.	+26	Dec.	−8

period 1843-53, monthly residuals, corrected for *non-cyclic change*, were obtained (see Table 4 and Fig. 4).

An inspection of the graph in Figure 4 shows that something must be wrong. An annual wave for H, with low values during the winter and high values during the summer, is evidently not correct. It is generally supposed that the annual wave in the monthly value of magnetic elements is due mainly to the annual distribution of the diurnal variation and, compared with the diurnal variation, the annual period of the 24-hour means from month to month is rather small. The most characteristic feature of this annual wave in H is the two maximum values in March and November with a chief and secondary minimum, respectively, at the times of the year when the Earth is at its greatest and shortest distance from the Sun. In the present case, however, we are not concerned with the annual wave of 24-hour values of H, but with the annual variation of monthly mean data for 09^h and 14^h. The question is, therefore, whether the average annual wave of H at 09^h, here found for Oslo, corresponds to that at other stations.

The annual variation of the 24-hour means is well known but this is not true in the case of a given hour. This subject, therefore, required special investigations. In this case of the annual variation of data for H at 09^h, we tabulated the pertinent data taken from the year book[4] of the Danish Magnetic Station at Rude Skov. As this station was not established until the beginning of the present century, data for the epoch 1843-53 were not available. Accordingly we chose the 11-year period 1920-30, a series which can be compared directly with the corresponding data for Oslo. It was found that the annual wave for H at 09^h, obtained by use of such reduction-constants as are mentioned above, differed considerably from a corresponding curve for the Danish station and also from the result obtained for the magnetic station at Dombås ($\phi = 62° \, 05'$ north, $\lambda = 9° \, 06'$ east). (A general study was made of the annual variation of the value for each individual hour for each of the three elements D, H, and V at Dombås and the results of this investigation have been published.[5]

It is therefore clear that something must be wrong in the first reduction. The correct wave in H for 09^h is so small that an error in the scale-value cannot be responsible for this large annual variation and the

[4] Magnetisk Aarbog, Köbenhavn, Met. Inst.

[5] K. F. Wasserfall, On the annual period of magnetic elements, Terr. Mag., **42**, 43-44 (1937).

error must lie in the correction for temperature. The correctness of Hansteen's temperature-coefficients α and β for the bifilar magnet can hardly be doubted, but even if this were the case it would only mean a possible error to the third temperature-coefficient, λ, the value of which has been determined directly from the observed material. The method used is therefore adequate and the values from Figure 3 cannot be very far from what the material at hand actually demands. This may also be ascertained by plotting observed absolute values for the different times of the year. During the three years 1864-66 Hansteen made absolute observations for H frequently and many of these observations were obtained between 09^{h} and 10^{h}; during 1865 there were 21 observations taken about this time of the day and they are fairly well distributed throughout the year. In spite of a considerable individual variation in the data for H from observation to observation, the comparatively large annual wave with low value during the winter and high during the summer, is also plainly discernible when the absolute data are plotted.

There can thus be no doubt that the error is to be sought in the absolute data. In Figure 3 we have used data for B_h, which according to equation (24) is equal to $(H-h)$ where the data for H are reduced from Hansteen's observations of oscillation. Had an incorrect temperature coefficient for Dollond's cylinder been used in reducing these data, the erroneous result for the temperature-coefficient for the suspension, λ, would be satisfactorily explained.

It will be shown later that a change in the value of the temperature-coefficient of Hansteen's oscillation-magnet from $\alpha = 0.000654$ to $\alpha = 0.000621$ seems reasonable (see Fig. 12) and this change in α would correspond to a change in the logarithmic coefficient b_s from 14.9 to 13.5 per 1°.0 R. If a rereduction for Hansteen's observed data for oscillation is made, the absolute data for H show a more reasonable variation during the year and a value for λ is obtained which corresponds to the one from Figure 3 reduced to about half of its former value or, in other words, from 5.4 to 2.6 per 1°.0 R (see Table 5 and Fig. 5).

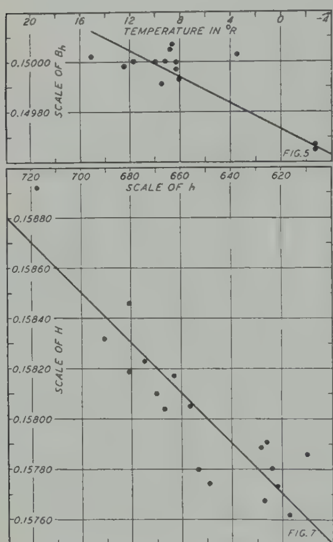
Table 5 gives the first two and the last three columns of Table 3,

TABLE 5

Year	Date	t_r	h	H	B'_h
		° R	γ	*cgs*	*cgs*
1844	May 21	9.1	519	0.15519	0.15000
	21	9.4	526	0.15517	0.14991
1845	May 21	8.6	533	0.15540	0.15007
	21	8.8	537	0.15547	0.15005
	22	8.1	498	0.15491	0.14993
	Nov. 15	3.4	529	0.15532	0.15003
1846	Jan. 31	−2.7	536	0.15501	0.14965
	31	−2.7	537	0.15504	0.14967
1848	May 27	9.9	665	0.15665	0.15000
1850	Apr. 20	8.3	574	0.15573	0.15000
	20	8.3	577	0.15573	0.14996
1851	June 26	15.1	582	0.15584	0.15002
	July 18	11.7	613	0.15613	0.15000
	Sep. 4	12.4	634	0.15632	0.14998

besides the column for t_r. The figures under the heading h and t_r are the same as before, but in the column for H we have now introduced the new data in which 13.5 is used instead of 14.9 for the logarithmic temperature-coefficient of Dollond's cylinder. The plot in Figure 5 for B_h and t_r gives $\lambda = 2.6\gamma$ per 1.°0 R for the first month of 1848.

The influence of the temperature-variation on the torsion of the suspension is important. The final compilations for the entire period 1843-76 using seven trustworthy series are shown in Table 6. The



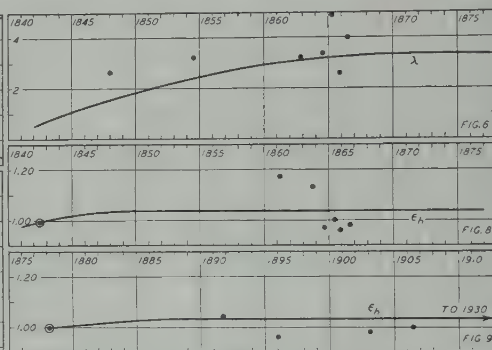


FIG. 5—INFLUENCE OF TEMPERATURE ON SUSPENSION, MAY 21, 1844 TO SEPTEMBER 4, 1851, USING TEMPERATURE-COEFFICIENT=13.2 FOR REDUCTION OF H

FIG. 6—VALUE OF λ USED IN FINAL REDUCTION OF EYE-READINGS, 1843-76

FIG. 7—RELATION BETWEEN OBSERVED DATA FOR H AND CORRESPONDING EYE-READINGS OF h, REDUCED FOR INFLUENCE OF TEMPERATURE, FEBRUARY 26 TO JULY 22, 1865

FIG. 8—VALUE OF ϵ_h USED IN FINAL REDUCTION OF EYE-READINGS, 1843-76

FIG. 9—VALUE OF ϵ_h USED IN FINAL REDUCTION OF EYE-READINGS, 1878-1930

number of data in each series is given as well as the number of data "disqualified" because they were too far from the average line through the points.

TABLE 6

No.	From		To		Referred to		λ	Temp.-diff.	No. of data	Disq. data
	Year	Date	Year	Date	Year	Month		°R		
I	1844	May 21	1851	Sep. 4	1848	Jan.	2.6	17.8	14	0
II	1855	Apr. 8	1855	Oct. 11	1855	June	3.2	13.5	7	0
III	1861	Nov. 24	1863	May 20	1862	Oct.	3.2	14.3	23	7
IV	1864	Apr. 3	1864	Dec. 23	1864	Aug.	3.4	16.4	22	2
V	1865	Feb. 26	1865	July 22	1865	May	4.9	17.6	18	0
VI	1865	Sep. 8	1865	Dec. 18	1865	Nov.	2.6	11.2	16	0
VII	1866	Apr. 25	1866	Nov. 6	1866	July	4.0	11.0	21	1

Taking as a basis the results for λ in Table 6 and considering some systematic trials of reduction of the eye-readings in which varying values for λ were used, values for λ were finally adopted according to

the curve in Figure 6. As the material at hand seems to indicate a curved line with comparatively small values for λ during the earlier years, gradually increasing to a constant value of 3.3γ per $1°.0$ R, we have used this form for the curve, which is also in agreement with the final curve for the scale-value ϵ_h according to investigations to be treated later.

During the entire interval 1878-1930 there seems to be only one small series of data for H and h suitable for controlling the value of λ. The series comprises only six data from July 21 to November 19, 1900, and the relation between B_h and t_r, indicated by the average line through the points, may be put at 3.9. Investigations of reductions with varying values for λ seem to indicate that the most probable value for λ is that one which, according to the curve in Figure 6, was used for the final reduction of the years preceding the accident to the magnet in 1876. This value was $\lambda = 3.3\gamma$ per $1°.0$ R.

The scale-value for the eye-readings of the bifilar magnet—The method according to which the scale-value, ϵ_h, has been controlled will be understood from the example given in Table 7 and in Figure 7. In the column under the heading h' we have entered the eye-readings expressed in

TABLE 7

Date	h'	t_r	c_a	c_λ	h	H
1865	*pars*	° R	*pars*	*pars*	*pars*	γ
Feb. 26	765	− 3.1	− 92	−16	657	15805
26	771	− 2.6	− 86	−15	670	15810
27	746	− 2.3	− 83	−14	649	15774
27	760	− 1.9	− 79	−14	667	15804
Mar. 23	714	− 1.7	− 77	−13	624	15780
23	735	− 1.0	− 70	−12	653	15780
Apr. 11	656	+ 2.6	− 29	− 5	622	15773
11	710	+ 2.9	− 25	− 4	681	15819
22	617	+ 5.0	0	0	617	15762
May 22	544	+10.6	+ 73	+11	628	15788
22	591	+11.0	+ 78	+12	681	15846
June 12	535	+10.0	+ 65	+10	610	15786
12	607	+10.6	+ 75	+11	691	15832
19	517	+12.2	+ 95	+14	626	15791
19	558	+12.7	+102	+15	675	15823
July 17	494	+13.7	+116	+17	627	15768
17	582	+13.8	+118	+18	718	15892
22	516	+14.5	+128	+19	663	15817

pars (p), according to the mean value entered in the note-book for observations and computed as shown in Table 1. In the next column, under t_r, we have the temperature as read on the thermometer above the pole of the magnet and after application of two corrections for influence of the varying temperature on the magnet and on the torsion of the suspension, the corrected eye-readings are given under the heading h. The last column gives the corresponding observed data for H. The values for H and h are plotted in Figure 7 and the inclined line through the points gives the scale-value $\epsilon_h = 1.00\gamma$ per pars.

For the entire period 1843-76 we have found six series of data for h and H suitable for controlling the scale-value, ϵ_h, as shown in Table 8.

Table 8

No.	From		To		Referred to		ϵ_h	Max. diff.	No. of data	Disq. data
	Year	Date	Year	Date	Year	Month				
							γ	γ		
I	1860	May 28	1861	July 31	1861	Jan.	1.17	97	13	0
II	1861	Nov. 24	1863	Apr. 9	1862	Aug.	1.13	122	21	1
III	1864	Apr. 3	1864	Dec. 21	1864	Aug.	0.97	142	22	1
IV	1865	Feb. 26	1865	July 22	1865	May	1.00	130	18	0
V	1865	Sep. 8	1865	Dec. 18	1865	Nov.	0.96	98	16	0
VI	1866	Apr. 25	1866	Nov. 6	1866	Aug.	0.98	124	21	0

Under the heading "Max. diff." is entered the total difference between the lowest and highest values for H in the series in question, while the significance of the two last columns will be understood from what has been said regarding Table 6.

The finally adopted graph of Figure 8 for ϵ_h is based on Hansteen's observation for the scale-value in April, 1842, and the resulting six control-values, given in Table 8.

During 1878-1930 there are generally long intervals between the observations and many changes in the base-line values. We have found only four short series of observations suitable for extracting control-

Table 9

No.	From		To		Referred to		ϵ_h	Max. diff.	No. of data	Disq. data
	Year	Date	Year	Date	Year	Month				
							γ	γ		
I	1891	Sep. 8	1891	Sep. 23	1891	Sep.	1.04	34	10	1
II	1896	Aug. 13	1897	July 16	1897	Feb.	0.96	44	8	0
III	1902	June 21	1903	Aug. 14	1903	Jan.	0.98	67	6	2
IV	1905	Sep. 1	1906	Aug. 3	1906	Apr.	1.00	48	6	2

values for ϵ_h (see Table 9). Using as basis Fearnley's observation of January, 1878, and the four control-data in Table 9, the graph of Figure 9 was finally adopted. Starting with 1878 using Fearnley's value the adopted curve gradually increases to the value 1.04, which corresponds to that assumed for the instrument when it fell in 1876. There might be a question as to whether it would not have been more correct to keep a constant value, as for example Fearnley's, for the entire period 1878-1930, but as the graph had to be adopted before the final reduction was begun, it was decided that the form indicated in Figure 9 was the best. In any case the results would be but slightly altered had a constant value indicated by Fearnley's observation been used instead of that given by the graph in Figure 9.

The absolute observations

Hansteen's instrument—Hansteen's absolute instrument was primitive but the accuracy of his observations with it is nevertheless good.

The instrument has been described in detail by Hansteen[6] and, as the reference is not generally accessible, by the present author in a brief description to which the reader is referred[7] (see Fig. 10). Only observations of oscillation could be made with this instrument and they were made by the eye as there was no telescope. Hansteen observed the

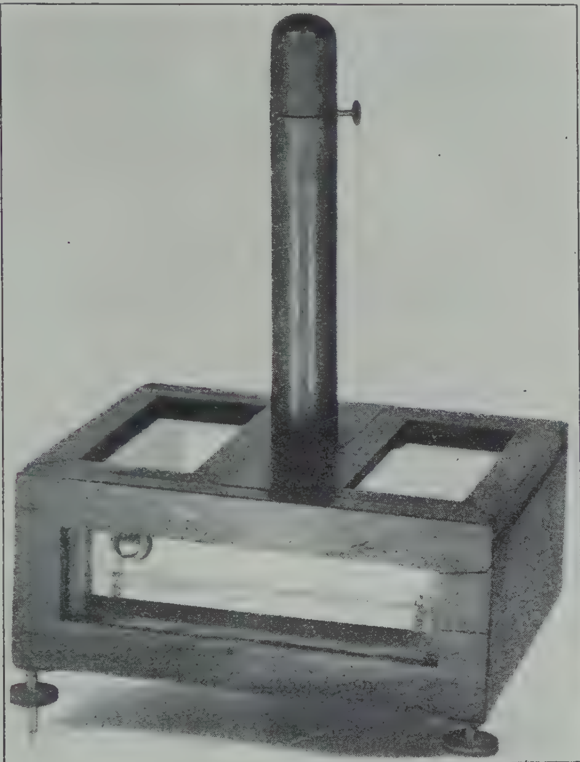


FIG. 10—HANSTEEN'S OSCILLATION-BOX NOW PRESERVED AS A RELIC OF HIS PIONEER WORK IN MAGNETIC RESEARCH AND SURVEY.

time required for 300 (half) oscillations and his observations at Oslo Observatory from 1843 to 1866 were all made with the same magnet. He refers to this magnet as Dollond's steel cylinder. The magnet was bought about 1819 and was manufactured by the London firm Dollond.

The temperature-coefficient of Dollond's cylinder-magnet—The value of the temperature-coefficient for Dollond's cylinder is stated by Hansteen on various occasions. In a paper[8] published in 1842 Hansteen states: "By observing the time of oscillation of Dollond's cylinder inside an apparatus in which the air could be alternately heated and

[6]Nyt Mag. Naturv., Kristiania, **4**, 271-277 (1842).

[7]K. F. Wasserfall, Hansteen's magnetic instrument, Terr. Mag., **42**, 45-47 (1937).

[8]Nyt Mag. Naturv., Kristiania, **3**, 103-104 (1842).

cooled, I found that the time of oscillation when the temperature was rising increased so much that denoting by T the time of a certain number of oscillations at a certain normal temperature α and by T' the time for the same number of oscillations at a temperature $(\alpha+10)$, both according to a Réaumur thermometer, then

$$\log T' = \log T + 149 \tag{26}$$

the correction applied to the fifth decimal of log T." In another article[8a] he gives the temperature-coefficients of Dollond's cylinder and of three other magnets; for the Dollond magnet he gives $\alpha = 0.000654$ and $s = 0.00007$ for the formula

$$M_0 = M(1-\alpha t) + s(t-t_0)^2 \tag{27}$$

This value gives $b_s = 14.8 \times 10^{-5}$ which is practically the same as above.

There is therefore no doubt about the value of the temperature-coefficient accepted by Hansteen but neither in his paper nor in the old documents have we been able to find the data on which the value is based. As there was no reason to doubt the correctness of Hansteen's value ($b_s = 14.9$) it was accepted, as above mentioned, in a preliminary reduction, but was later found to be too high. A control was therefore necessary. No data being available for this purpose, we have tried to determine whether the material left by Hansteen could be used to control the temperature-coefficient.

During 1864-66 Hansteen made absolute observations frequently and as these observations were made at temperatures ranging from about $-5°$ to $+20°$ there seemed possible a reliable control. Material suitable for obtaining the influence of temperature should be such that the time-interval between observations of high and low temperature would be comparatively short. In this case, however, the observations are distributed over the whole year, so that observations with low temperature occur during the winter and those with high temperature during the summer. Moreover the observations were made at different times of the day. Thus, it is clear that the observations had to be corrected because of the diurnal and annual variations.

As the constants of the eye-readings are dependent on the correctness of H and, even had a correct temperature-correction been used in reducing Hansteen's oscillations, there was not available a reliable graph for the annual variation for the single hours. It was necessary therefore to approximate this variation by means of another magnetic station at which the diurnal and annual variations would correspond more or less closely to those at Oslo. The Danish station, Rude Skov, was chosen and Figure 11 shows the graphs of the annual variation in H for every hour between 09^h and 21^h, local mean time, for the year 1933 which corresponds more or less in the sunspot-period to the year in question for Oslo, namely, 1855.

Monthly mean data for H for each hour between 08^h and 21^h, were extracted from the Danish year book[9] month by month. Residuals from the annual mean of each special hour series were corrected for

[8a]Nyt Mag. Naturv., Kristiania, **3**, 268 (1842).

[9]Magnetisk Aarbog 1933, København, Met. Inst. (1934).

non-cyclic change and plotted as in Figure 11. Corrections were made to Hansteen's data for H by aid of these curves (see Table 10 under c_1). The values, H'', of horizontal intensity in Table 10 are from Hansteen's oscillation-observations, using 14.9 as the logarithmic temperature-coefficient. The correction for secular variation is entered under the

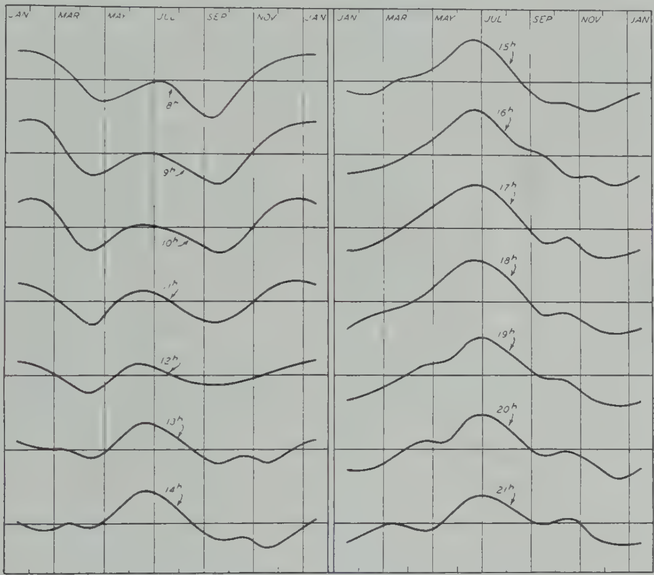


FIG. 11—ANNUAL WAVE OF EVERY HOUR FOR H BETWEEN 8^h AND 21^h, LOCAL MEAN TIME, FOR RUDE SKOV OBSERVATORY, 1933 VERTICAL SCALE: 0 10 20 30γ

heading c_2. The corrected value for H and the corresponding temperature-reading are given in the last two columns.

The data for H' and t_a in Table 10 are plotted in Figure 12. The comparatively large spreading of the points is due both to the aperiodic variation in H and to the inaccuracy of the observations so that we can hardly expect a better result. The resulting average line adopted seems reasonably reliable because of the large interval between the lowest and highest temperatures (26°). Accordingly we may estimate the relation between $\triangle H'$ and $\triangle t$ at 3.3γ per 1° R, which shows that Hansteen's temperature-coefficient, $\alpha=0.000654$ in equation (27), must be 0.000033 too high; hence the correct value is $\alpha=0.000621$, as above stated. The corresponding logarithmic coefficient is $b_s=13.5\times10^{-5}$.

Magnetic moment of Dollond's cylinder—Hansteen reduced his observations by means of the formula

$$\log H=C_s-2\log T_0 \tag{28}$$

where T_0 denotes the corrected time for 300 oscillations. Corrections are made for temperature-variation and rate of chronometer, besides reduction to infinitely small arc. As Hansteen used a single silk fiber for suspension, he did not find it necessary to correct for torsion. No

TABLE 10

Date	Time	H''	c_1	c_2	H'	t_a
1865	h m	cgs	γ	γ	γ	°R
Feb. 26	9 58	0.15790	−11	− 3	15776	− 0.2
26	17 03	(0.15798)	+ 7	− 3	.....	+ 1.4
27	9 56	0.15758	−11	− 3	15744	− 0.3
27	17 05	0.15791	+ 7	− 3	15795	+ 1.0
Mar. 23	10 00	0.15768	+ 2	− 4	15766	+ 1.6
23	18 10	0.15768	+ 3	− 5	15766	− 1.4
Apr. 11	10 06	0.15778	+10	− 5	15782	+ 9.8
11	18 56	0.15817	− 4	− 6	15807	+ 6.6
22	10 01	0.15766	+10	− 7	15769	+ 9.5
May 22	9 59	0.15813	+ 2	− 8	15807	+19.6
22	20 33	(0.15860)	− 2	− 8	.....	+14.7
June 12	10 03	0.15795	− 1	− 9	15785	+12.1
12	20 46	0.15840	−11	− 9	15820	+11.6
19	10 04	0.15809	− 1	−10	15798	+16.5
19	21 06	0.15833	−11	−10	15812	+12.7
July 17	10 00	(0.15791)	+ 1	−11	.....	+19.2
17	19 54	(0.15905)	−13	−11	.....	+14.0
22	10 08	0.15845	+ 1	−12	15834	+21.4
Aug. 3	9 47	(0.15386)	+ 5	−13	.....	+17.2
22	10 00	0.15814	+ 5	−14	15805	+14.7
22	19 16	(0.15861)	− 6	−14	.....	+12.0
Sep. 8	10 04	(0.15769)	+10	−15	.....	+14.8
8	18 29	0.15838	+ 4	−15	15827	+14.6
14	10 00	0.15792	+10	−16	15786	+12.2
Oct. 11	10 00	(0.15719)	+ 6	−17	.....	− 0.2
11	16 55	0.15770	+ 3	−17	15756	+ 0.6
17	10 08	(0.15731)	+ 6	−18	.....	+ 1.9
17	16 32	0.15765	+ 5	−18	15752	+ 1.6
Nov. 10	10 04	0.15759	− 7	−19	15747	− 2.1
10	15 39	0.15761	+10	−19	15752	− 1.2
12	10 11	0.15766	− 7	−19	15740	+ 0.0
25	10 00	0.15753	− 7	−20	15726	− 1.1
25	11 58	0.15812	0	−20	15792	+ 1.6
Dec. 12	10 08	0.15772	−11	−21	15740	− 4.2
12	14 41	0.15777	+ 6	−21	15762	− 4.2
18	9 58	0.15815	−11	−22	15782	− 1.2
18	14 44	(0.15810)	+ 6	−22	.....	− 1.2

special correction can be found which was applied for induction but such a correction is probably included in the constant C_s.

Hansteen observed[10] with Dollond's cylinder at the Göttingen Magnetic Observatory of Gauss. During August and September, 1829, about 100 observations for oscillation were collected, by means of which he could calculate the value of C_s in equation (28), using H as determined by the Göttingen Observatory. The final value for C_s, based on the observations at Göttingen in 1831, was not directly stated in the above reference and there seems to have been some uncertainty concerning the value which should be used, but in reducing his observations at the Oslo Observatory during 1843-48, Hansteen used values the average of which is $C_s = 5.00900$.

Hansteen also made observations at Göttingen in 1834 and the following quotation from a lecture[11] in May 1859 before *Videnskabselskabet*

[10]Nyt Mag. Naturv., 3, 236-253 (1842).

[11]Kristiania, Forh. Vid. selsk., 1854, Bind 1858-59, p. 110.

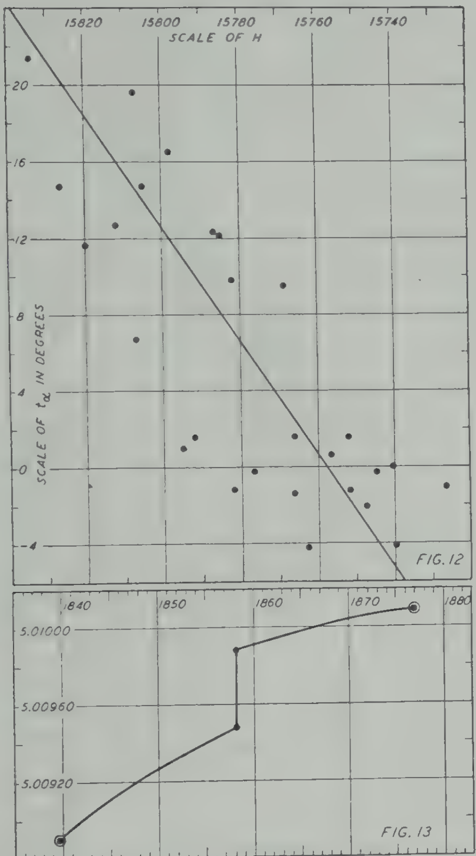


FIG. 12—GRAPH TO DETERMINE ERROR IN TEMPERATURE-COEFFICIENT OF HANSTEEN'S OBSERVATIONS
FIG. 13—CONSTANT C_s OF DOLLOND'S CYLINDER, 1839-76

i Oslo, contains a valuable hint regarding the constant C_s: "By means of values for H and T at Göttingen in 1834 and 1839, København in 1845, and seven observations from Kristiania in 1840-50, it was found, that the constant C_s for Dollond's cylinder had slightly increased, indicating that its magnetic moment had decreased a little. The value may be found from

$$\log C_s = 6.008087 + 12.26(t-1834) - 0.38(t-1834)^2 \tag{29}$$

where the factors of the last two members are units of the fifth decimal."

Assuming that this formula holds good between 1834 and 1843, when our series begins, the constant C_s for 1843 would be 6.00907 expressed logarithmically with reference to H in Gauss units. Our adopted value, expressed logarithmically with reference to H given in CGS is thus $C_s = 5.00890$ for 1843. Having fixed the value for C_s for 1843, how did the magnet behave during 1843-76? Dollond's cylinder was made about 1819 and was thus a comparatively old magnet in 1843; the rate of

decrease in its magnetic moment should then have been low. The graph adopted for its magnetic moment (Fig. 13) depends upon the fixed points at the beginning and at the end of the curve and upon the amount of the sudden change about 1858. The adopted value for 1839 is 5.00890. The last value of the graph depends upon an indirect comparison with magnetometer Elliott 38. This comparison is by no means so good as that at Göttingen, but affords a good idea of the probable decrease of the magnetic moment of Dollond's cylinder. We may also refer to investigations made at Potsdam[12] on such changes in the magnetic moment with time. With reference to the sudden change in 1858, Hansteen states in a footnote in his observation-book: "There must have occurred a permanent change in the magnetic surroundings during the last months of the year 1858, probably in October." Hansteen evidently did not suspect any change in the magnetic moment of Dollond's cylinder; this is, however, not strange, since we know that he always treated the magnet with the utmost care. Nevertheless some unknown accident must have befallen the magnet causing a permanent loss of magnetism in October, 1858. Using the fifth decimal of the logarithm as unit, the loss was estimated at 40 units, equivalent to 15γ.

The indirect comparison between observations with Dollond's cylinder and those obtained with magnetometer Elliott 38 consists of 21 observations in the last series with Dollond's cylinder between April 25 and November 6, 1866. A good base-line value, $B_h = 0.14986$, resulted for the relative readings. The first observation with magnetometer Elliott 38 by C. Wille on October 2, 1876, gave $H = 3.4664$ British units or 0.15983 CGS unit. Our mean monthly values of H for June, 1876, are 0.15984 at 09^h and 0.16003 at 14^h. The constants used for the reduction of the observation with Elliott 38 were determined at Kew[13] in 1875. Thus it is clear that the comparison between Hansteen's last value with Dollond's cylinder and Wille's first observation with Elliott 38 in 1876 is dependent upon the accuracy of extrapolation of base-line values during the interval of nearly ten years from 1866-76.

Reduction-constants for Elliott 38—Wille's instrument, Elliott 38, is still in good condition and is in use as station-instrument at the Dombås Observatory. The constants were redetermined on various occasions—thus by A. Steen in 1892 at Pavlovsk, by S. Saeland in 1923 at Rude Skov, etc. Based on the temperature-coefficient $\alpha = 0.000234$ per 1°.0 C and the moment of inertia $K = 303.37$, the magnetic moment, M, and the constant P, are given in Table 11; these data are from graphs based on all available and trustworthy material. The values for M show abrupt changes of 5.7 units in 1910, of 9.7 units in 1917, and of 4.3 units in 1923. In Table 11 the entries are from the graphs for M' and M.

TABLE 11

Year	M'	Corr.	M	P
1875	998.7	0.0	998.7	24.82
1885	912.9	0.0	912.9	23.81
1895	857.5	0.0	857.5	23.30
1905	827.6	0.0	827.6	23.05
1915	812.6	− 5.7	806.9	22.89
1925	806.3	−14.0	792.3	22.81

All the observations at the Oslo Observatory were taken at the two deflection-distances, namely 1.0 and

[12] Ad. Schmidt, Berlin, Veröff. Met. Inst., No. 203 (1908).

[13] C. Wille, Magnetiske observationer, Det Astronomiske Observatoriums samlebind No. A, 101.

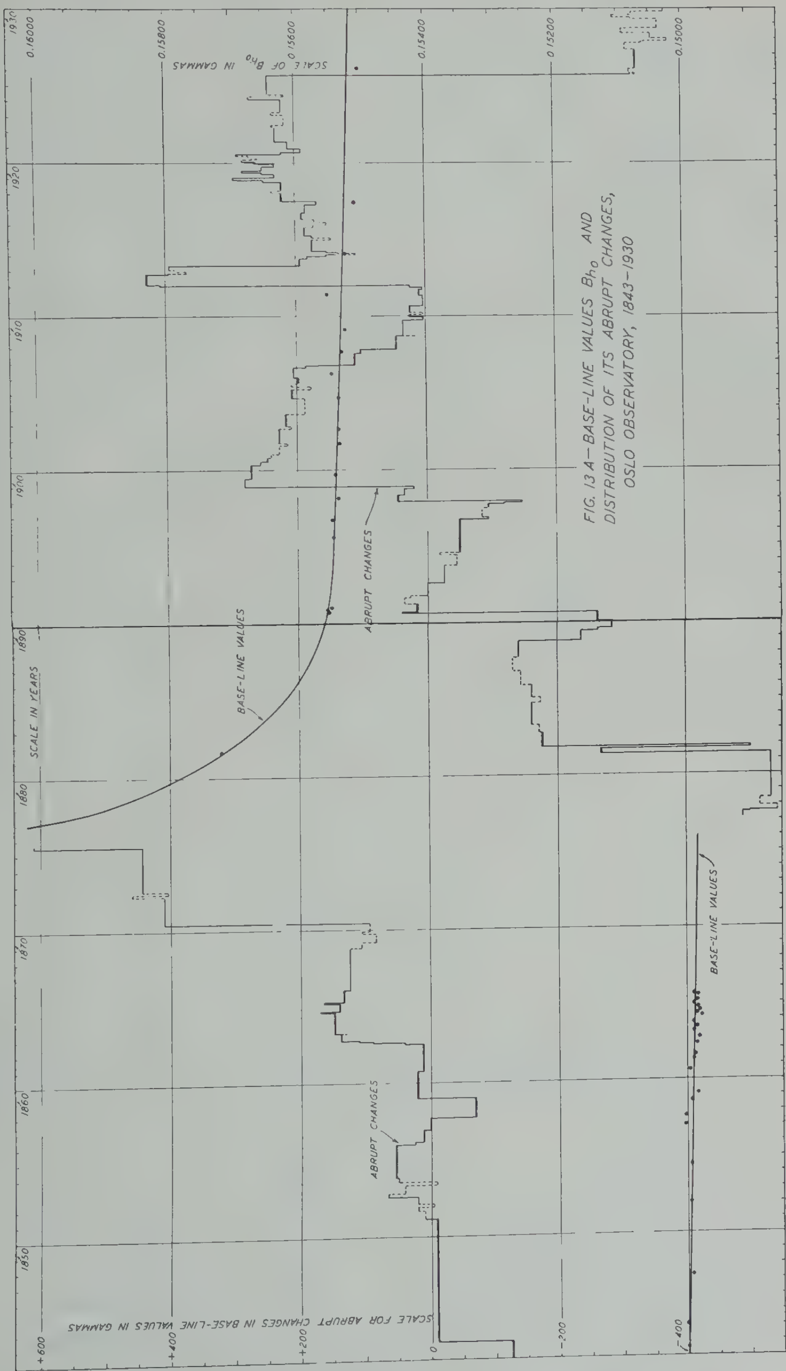


FIG. 13 A—BASE-LINE VALUES B_{ho} AND DISTRIBUTION OF ITS ABRUPT CHANGES, OSLO OBSERVATORY, 1843-1930

1.3 feet (30.472 and 39.613 cm), as measured by Professor Saeland at Oslo in 1892. Steen's value for the induction-constant determined at Pavlovsk in 1892 was $k=0.007909$. In the reduction according to the formulas

$$\log H=C_a-\log \sin \phi_0 \quad \text{and} \quad \log H=C_s-2 \log T_0 \tag{30}$$

we have used $b_a=12.7$ and $b_s=7.8$ as logarithmic temperature-coefficients and $C_1=8.75872$ and $C_2=8.41251$ for the two distances 1.0 and 1.3 feet, respectively, and $C_s=0.57737$, the three constants C_1, C_2, and C_s, being referred to 1925.5.

The absolute instrument used for the observation in 1882—As mentioned above, the base-line value was subjected to a large, gradual change during 1878-90 (see Fig. 13*A*). The form of the curve for B_h is more or less estimated, since between 1878 and 1891 there were only two observations—both made in 1882. The first on July 7, 1882, by H. Mohn does not state the instrument used, but as it is not known that the Observatory possessed at that time any instrument other than Hansteen's oscillation-box and magnetometer Elliott 38, it must be assumed that the observation was made with Dollond's cylinder. Mohn states that his observation gave $H=0.16033$, with a corresponding eye-reading of the bifilar magnet equal to 478 pars at 11°.3 R. Now this value for H is much too low but may be explained on the assumption that the observation was actually made with Dollond's cylinder and reduced by equation (18) using a *too low* value for C_s, for instance, $C_s=5.00960$. The graph for C_s (Fig. 13) shows this value reasonable, if the gradual loss of magnetism is considered but not the abrupt change in 1858. If our assumption is correct, a correction of about $+20\gamma$ would give the more reasonable value, namely, $H=0.16053$.

The next observation was made by Fearnley as of October 12, 1882. He obtained $H=0.16054$ with a corresponding eye-reading of the bifilar magnet equal to 469 pars at 7°.6 R. This corroborates to a certain extent the value by Mohn in July. Fearnley's result is really the mean of a series of measurements made between October 5 and 18, 1882, using the "Gauss's unifilar" and magnets I, II, III, and IV.

What is meant by "Gauss's unifilar" is not quite clear, but the magnets are evidently Hansteen's so-called "reserve magnets." These magnets were sent to all parts of the world by Hansteen whenever there was an opportunity of obtaining magnetic data; changes in their magnetic moments were controlled by comparison with Dollond's cylinder, as soon as they were returned to Hansteen. The constants of these magnets were given on various occasions in the *Magazin for Naturvidenskaberne*. From documents left by Fearnley we have determined the values he used for the magnetic moments of the magnets; these data for 1882 are given in Table 12 as also those given by Hansteen for 1855. Fearnley's methods of determing M are not known but examination of the column headed "Difference" indicates them as reasonable. The value of M for Magnet III used

TABLE 12

Magnet	Magnetic moment 1855	Magnetic moment 1882	Difference
I	482.63	463.37	−19.26
II	502.98	494.48	−11.50
III	443.47	444.20	+ 0.75
IV	430.82	425.07	− 5.75

TABLE 13

Date	Mag.	h	t_r
1882		*pars*	°
Oct. 5	II	417	9.6
7	II	446	9.1
9	I	461	8.5
10	I	454	8.1
12	IV	478	7.5
13	IV	483	7.6
14	III	482	7.0
17	II	508	6.0
18	II	493	5.6

by Fearnley seems erroneous when compared with that given by Hansteen for 1855; on the other hand, Fearnley's value for Magnet I seems to be too low, considering that it was a very old magnet. The differences from Table 12 give a mean loss of about eight units, which may be accepted as reasonable. The mean values of h and t_r from Table 13 for the eye-readings of the bifilar magnet correspond with those given above. Thus we can accept Fearnley's value for October 12, 1882, as it agrees well with Mohn's value of July only if the abrupt change in 1858 is accepted.

CALCULATION OF THE BASE-LINE VALUE

Period, 1843-76—The observations given in Table *A* were made by Hansteen with his Dollond cylinder during 1843-76. The observed time for 300 oscillations in seconds is given in column "T." Column "t_a" contains the mean value for the temperature during the observation. The values for the constant C_s expressed logarithmically and the values for H are derived by means of equation (28) and the corresponding eye-reading, respectively. Under the heading ϵ_h we have the scale-value of the relative data, followed by the temperatures for the eye-readings designated as t_r. Under the heading h, are the corrected eye-readings, now expressed in γ, reduced by the formula

$$\log T_0 = \log T - b_s t \times 10^{-5} \qquad (31)$$

and, finally, the calculated base-line values are entered under "B_h" [the last are computed by equation (24).] Hansteen occasionally used 200 oscillations, instead of 300, and consequently, it was necessary to find the corresponding value for C_s. This was done by comparison.

Finally under the heading $\triangle$ we have introduced corrections for all

TABLE 14

Year	Month	B_{h_0}	No.	Year	Month	B_{h_0}	No.
		cgs				*cgs*	
1843	Aug.	0.15001	3	1863	Oct.	0.14981	7
1845	Jan.	0.15002	5	1864	Mar.	0.14989	6
1848	Apr.	0.14992	5	1864	June	0.14985	7
1853	Jan.	0.14995	5	1864	Sep.	0.14989	7
1855	July	0.14995	7	1865	Mar.	0.14977	7
1858	Jan.	0.15003	5	1865	May	0.14984	7
1858	July	0.15003	6	1865	July	0.14980	7
1859	Aug.	0.14994	6	1865	Oct.	0.14982	7
1860	Feb.	0.14983	4	1865	Dec.	0.14992	7
1861	Aug.	0.14997	7	1866	Mar.	0.14984	6
1862	May	0.14991	6	1866	July	0.14982	9
1862	Aug.	0.14989	6	1866	Aug.	0.14990	8
1863	May	0.14986	7				

Table A—*Base-line values, Oslo Observatory, 1843-1866*

Year	Date	Time	T	t_a	C_s	H	h	ϵ_h	t_r	h	B_h	$\triangle$	B_{h_0}
		h m	sec	°		cgs	pars	γ	°	γ	cgs	γ	cgs
1843	Apr. 22	13 08	812.54	9.5	5.00905	0.15513	650	0.992	3.9	629	0.14884	+125	0.15009
	22	13 27	813.28	12.0	5.00905	0.15503	651	0.992	4.0	632	0.14871	+125	0.14996
	25	10 10	812.98	8.2	5.00905	0.15483	625	0.992	4.5	613	0.14870	+125	0.14995
	25	10 30	812.03	9.5	5.00905	0.15525	623	0.992	4.6	612	0.14913	+125	....
1844	May 21	13 08	484.66	16.4	4.55900	0.15519	469	0.995	9.1	523	0.14986	+ 10	0.14996
	21	13 50	485.49	22.4	4.55900	0.15517	472	0.995	9.4	530	0.14987	+ 10	0.14997
1845	May 21	10 55	484.30	16.0	4.55904	0.15540	488	0.998	8.6	537	0.15003	+ 10	0.15013
	21	11 24	813.41	17.2	5.00912	0.15542	490	0.998	8.8	541	0.15001	+ 10	0.15011
	22	10 36	485.17	16.8	4.55904	0.15491	459	0.998	8.1	501	0.14990	+ 10	0.15000
	Nov. 15	11 40	810.87	3.8	5.00913	0.15532	549	0.999	3.4	527	0.15005	+ 10	....
1846	Jan. 31	13 42	810.54	− 0.5	5.00914	0.15501	624	1.000	− 2.7	534	0.14967	+ 10	0.14977
	31	14 00	810.61	− 0.1	5.00914	0.15504	625	1.000	− 2.7	535	0.14967	+ 10	0.14977
1848	May 27	20 20	809.91	15.0	5.00921	0.15665	599	1.005	9.9	673	0.14992	+ 10	0.15002
1850	Apr. 20	10 51	811.75	8.5	5.00927	0.15573	527	1.010	8.3	580	0.14993	+ 10	0.15003
	20	11 16	810.71	8.8	5.00927	0.15573	530	1.010	8.3	583	0.14990	+ 10	0.15000
1851	June 24	09 27	813.41	21.0	5.00930	0.15584	440	1.011	15.1	602	0.14982	+ 10	0.14992
	July 18	14 00	812.80	21.4	5.00930	0.15613	519	1.011	11.7	626	0.14987	+ 10	0.14997
	Sep. 4	15 42	811.26	16.4	5.00930	0.15632	530	1.012	12.4	649	0.14983	+ 10	0.14993
1854	June 26	10 18	812.25	19.4	5.00937	0.15619	467	1.018	15.0	633	0.14986	+ 10	0.14996
	26	18 08	811.13	19.2	5.00937	0.15662	494	1.018	15.8	675	0.14987	+ 10	0.14997
1855	Apr. 8	09 49	809.07	5.0	5.00938	0.15642	630	1.019	1.9	598	0.15044	− 54	0.14990
	9	09 35	808.76	4.7	5.00938	0.15656	642	1.019	1.8	608	0.15048	− 54	0.14994
	Aug. 4	10 14	810.84	16.7	5.00939	0.15651	431	1.019	15.3	605	0.15046	− 54	0.14992
	5	17 18	808.92	14.2	5.00939	0.15699	462	1.019	15.1	633	0.15066	− 54	0.15012
	8	17 58	809.87	16.2	5.00939	0.15689	483	1.019	13.9	633	0.15056	− 54	0.15002
	Oct. 9	09 28	808.58	10.1	5.00939	0.15679	575	1.020	8.2	635	0.15044	− 54	0.14990
	11	09 24	808.61	8.2	5.00939	0.15661	573	1.020	7.3	619	0.15042	− 54	0.14988
1857	June 10	11 11	809.61	12.8	5.00943	0.15666	569	1.022	10.0	659	0.15007	− 11	0.14996
	10	17 13	808.08	12.8	5.00943	0.15726	603	1.022	11.2	713	0.15013	− 11	0.15002
	15	10 55	808.59	14.2	5.00943	0.15720	594	1.022	10.3	690	0.15030	− 11	....
	15	17 23	808.44	16.4	5.00943	0.15745	613	1.022	10.4	710	0.15035	− 11	....
1858	June 23	10 03	810.01	20.5	5.00945	0.15725	538	1.023	15.5	723	0.15002	0	0.15002
	23	17 49	805.18	22.6	5.00945	0.15933	726	1.023	15.7	917	0.15016	0	0.15016
	24	10 06	812.10	16.6	5.00945	0.15610	432	1.023	15.3	610	0.15000	0	0.15000
	24	17 56	806.15	10.6	5.00945	0.15791	611	1.023	14.8	785	0.15006	0	0.15006
	27	10 06	810.69	16.3	5.00945	0.15664	504	1.023	14.0	662	0.15002	0	0.15002
	27	18 07	808.10	13.2	5.00945	0.15735	565	1.023	14.3	728	0.15007	0	0.15007
	Aug. 5	18 21	807.74	13.8	5.00945	0.15760	586	1.024	14.0	746	0.15014	0	0.15014
	6	12 22	810.21	17.2	5.00945	0.15698	551	1.024	14.2	714	0.14984	0	0.14987
	6	18 43	807.81	16.2	5.00945	0.15786	619	1.024	14.3	785	0.15001	0	0.15001
1859	July 8	18 11	808.77	17.8	5.00987	0.15754	615	1.025	16.2	813	0.14941	+ 69	0.15010
	9	10 52	811.11	21.3	5.00987	0.15695	581	1.025	16.0	775	0.14920	+ 69	0.14989
	26	10 14	810.80	20.0	5.00987	0.15694	606	1.025	14.7	778	0.14916	+ 69	0.14985
	Aug. 30	09 42	811.81	12.6	5.00987	0.15637	562	1.025	13.3	708	0.14929	+ 69	0.14998
	30	12 30	811.45	16.6	5.00987	0.15677	594	1.025	13.5	745	0.14932	+ 69	0.15001
	30	17 37	811.11	15.6	5.00987	0.15685	617	1.025	13.7	771	0.14914	+ 69	0.14983
	Sep. 2	09 42	810.72	13.6	5.00987	0.15683	627	1.025	12.8	767	0.14916	+ 69	0.14985
	2	17 32	801.44	13.0	5.00987	0.16044	995	1.025	13.2	1150	0.14905	+ 69	0.14974
1860	May 28	13 35	809.30	14.1	5.00989	0.15709	623	1.026	9.4	707	0.15002	− 21	0.14981
	29	18 41	807.80	12.8	5.00989	0.15761	656	1.026	9.8	748	0.15013	− 21	0.14992
	July 13	09 34	809.87	18.4	5.00989	0.15714	505	1.026	14.6	673	0.15041	− 21	....
	14	11 11	809.71	16.9	5.00989	0.15708	506	1.026	14.9	680	0.15028	− 21	0.15007
	14	18 57	807.73	16.0	5.00989	0.15781	560	1.026	15.0	737	0.15044	− 21	....
	Nov. 8	10 13	806.96	0.0	5.00989	0.15733	658	1.027	5.5	680	0.15053	− 21	....
	8	14 28	806.74	1.2	5.00989	0.15733	671	1.027	5.5	693	0.15040	− 21	....

TABLE *A—Base-line values, Oslo Observatory, 1843-1866*—Continued

Year	Date	Time h	Time m	T	t_a	C_s	H	h	ϵ_h	t_r	h	B_h	$\triangle$	B_{h_0}
		h	*m*	*sec*	°		*cgs*	*pars*	γ	°	γ	*cgs*	γ	*cgs*
1861	June 27	10	22	810.59	17.0	5.00991	0.15723	521	1.027	14.4	689	0.15034	− 21	0.15013
	27	17	20	808.38	16.5	5.00991	0.15805	590	1.027	14.8	766	0.15039	− 21	....
	28	10	08	810.21	18.4	5.00991	0.15750	568	1.027	14.7	742	0.15008	− 21	0.14987
	28	17	18	809.32	23.0	5.00991	0.15757	584	1.027	15.0	763	0.14994	− 21	0.14983
	July 31	10	48	809.84	16.2	5.00991	0.15745	562	1.027	13.8	720	0.15025	− 21	0.15004
	31	17	30	808.50	15.1	5.00991	0.15787	617	1.027	14.2	783	0.15004	.....	0.14983
	Nov. 24	10	14	804.54	− 2.9	5.00991	0.15750	792	1.027	− 0.9	727	0.15023	− 11	0.15012
	24	14	57	805.56	− 1.8	5.00991	0.15743	794	1.027	− 0.3	738	0.15005	− 11	0.14994
1862	Apr. 7	10	08	807.59	6.5	5.00993	0.15731	762	1.028	1.4	729	0.15002	− 11	0.14991
	7	18	10	805.62	9.2	5.00993	0.15823	799	1.028	2.5	774	0.15049	− 11	....
	29	10	03	810.23	9.1	5.00993	0.15654	681	1.028	5.4	704	0.15054	− 11	....
	29	18	43	807.15	10.7	5.00993	0.15781	744	1.028	6.9	794	0.14987	− 11	0.14976
	May 7	10	07	809.52	15.4	5.00993	0.15740	664	1.028	8.0	729	0.15011	− 11	0.15000
	7	18	27	807.87	15.7	5.00993	0.15816	724	1.028	9.0	807	0.15009	− 11	0.14998
	June 25	10	14	809.98	18.2	5.00993	0.15746	612	1.028	12.0	741	0.15005	− 11	0.14994
	25	18	40	808.71	19.2	5.00993	0.15804	670	1.028	12.2	804	0.15000	− 11	0.14989
	July 8	18	33	808.06	14.1	5.00993	0.15802	659	1.028	12.0	790	0.15012	− 11	0.15001
	9	18	18	810.11	18.2	5.00993	0.15754	615	1.028	11.9	743	0.15011	− 11	0.15000
	26	10	14	809.82	15.5	5.00993	0.15729	590	1.028	12.4	726	0.15003	− 11	0.14992
	26	18	38	809.22	17.9	5.00993	0.15772	624	1.028	13.4	778	0.14994	− 11	0.14983
	Sep. 5	10	07	811.09	17.8	5.00993	0.15704	573	1.028	12.0	702	0.15002	− 11	0.14991
	5	17	53	809.32	19.5	5.00993	0.15782	655	1.028	13.0	802	0.14980	− 11	0.14969
1863	Mar. 28	10	08	806.45	4.2	5.00994	0.15761	747	1.029	2.2	727	0.15034	− 11	....
	28	10	23	805.13	1.0	5.00994	0.15795	820	1.029	2.7	810	0.14985	− 11	0.14974
	Apr. 8	18	14	805.36	6.3	5.00994	0.15826	825	1.029	5.0	849	0.14977	− 11	0.14966
	9	10	08	808.17	6.6	5.00994	0.15720	706	1.029	3.9	710	0.15010	− 11	0.14999
	9	18	24	807.21	9.0	5.00994	0.15779	764	1.029	4.8	784	0.14995	− 11	0.14948
	May 20	09	10	807.81	9.8	5.00994	0.15756	679	1.029	7.6	740	0.15016	− 11	0.15005
	20	18	20	807.13	11.2	5.00994	0.15795	724	1.029	8.1	793	0.15002	−108	0.14991
	Aug. 11	10	01	810.40	16.1	5.00995	0.15712	520	1.029	12.8	659	0.15053	−108	....
	Sep. 2	10	06	808.77	13.6	5.00995	0.15770	542	1.029	12.5	678	0.15092	−108	0.14984
	2	18	19	808.48	11.6	5.00995	0.15761	587	1.029	12.2	720	0.15041	−108	....
	5	17	59	807.99	12.8	5.00995	0.15774	570	1.029	12.3	705	0.15069	−108	....
	6	09	58	809.06	14.6	5.00995	0.15757	532	1.029	12.1	662	0.15095	−108	0.14987
	6	18	42	807.42	10.1	5.00995	0.15786	575	1.029	12.2	707	0.15079	−108	0.14970
	Oct. 8	10	04	806.75	3.8	5.00995	0.15746	593	1.030	6.9	637	0.15109	−138	0.14971
	19	16	30	806.89	5.9	5.00995	0.15780	604	1.030	7.3	654	0.15126	−138	0.14988
	Nov. 23	15	01	805.49	3.7	5.00996	0.15808	658	1.030	4.2	666	0.15142	−138	0.15004
	Dec. 18	10	10	805.20	− 4.2	5.00996	0.15754	699	1.030	0.0	646	0.15108	−138	0.14970
	18	14	38	806.14	− 2.2	5.00996	0.15739	675	1.030	0.2	625	0.15114	−138	0.14976
1864	Jan. 25	10	04	805.05	− 3.8	5.00996	0.15763	709	1.030	− 0.8	646	0.15117	−138	0.14979
	25	15	43	805.26	1.8	5.00996	0.15791	712	1.030	− 0.4	653	0.15138	−138	0.15000
	Apr. 3	09	58	806.76	4.2	5.00996	0.15755	647	1.030	1.0	608	0.15147	−148	0.14999
	3	18	30	805.62	3.7	5.00996	0.15785	703	1.030	1.6	674	0.15111	−148	0.14963
	5	10	00	806.70	2.6	5.00996	0.15743	645	1.030	0.4	597	0.15146	−148	0.14998
	5	18	33	803.99	0.6	5.00996	0.15877	731	1.030	1.2	687	0.15190	−148	....
	27	10	07	809.06	15.0	5.00996	0.15760	579	1.030	6.2	616	0.15144	−148	0.14996
	27	19	28	807.38	12.2	5.00996	0.15791	634	1.030	7.1	685	0.15106	−148	....
	May 18	09	58	809.64	18.0	5.00997	0.15764	576	1.030	8.4	647	0.15117	−148	0.14969
	18	20	08	806.11	11.6	5.00997	0.15836	617	1.030	9.0	699	0.15137	−148	0.14989
	20	10	10	808.63	14.4	5.00997	0.15772	572	1.030	8.2	641	0.15131	−148	0.14983
	June 23	14	08	810.63	20.2	5.00997	0.15740	502	1.030	12.2	634	0.15106	−148	....
	23	16	11	806.78	18.4	5.00997	0.15869	577	1.030	12.3	714	0.15155	−148	0.15007
	July 8	09	57	808.96	20.2	5.00997	0.15810	504	1.030	14.8	680	0.15130	−148	0.14982
	8	20	08	807.33	21.0	5.00997	0.15883	556	1.030	14.6	731	0.15152	−148	0.15004
	12	10	00	810.33	15.8	5.00997	0.15719	488	1.030	14.2	655	0.15064	−148	....
	12	20	12	806.88	15.5	5.00997	0.15839	553	1.030	14.6	728	0.15111	−148	0.14963
	24	09	57	809.00	17.7	5.00997	0.15786	473	1.030	14.5	645	0.15141	−148	0.14993
	24	20	14	806.58	14.9	5.00997	0.15845	524	1.030	14.6	698	0.15147	−148	0.14999
	Aug. 15	19	06	808.88	17.5	5.00997	0.15795	537	1.030	13.1	676	0.15119	−148	0.14971
	16	10	03	809.40	19.4	5.00997	0.15785	494	1.030	13.0	639	0.15146	−148	0.14998
	Oct. 22	16	21	805.84	2.9	5.00997	0.15785	632	1.030	4.5	644	0.15141	−148	0.14993
	Dec. 21	10	15	802.91	− 4.4	5.00998	0.15825	747	1.030	− 1.6	674	0.15151	−148	0.15003
	21	14	42	805.13	− 2.7	5.00998	0.15757	719	1.030	− 1.6	645	0.15112	−148	0.14964

Table A—*Base-line values, Oslo Observatory, 1843-1866*—Concluded

Year	Date	Time		T	t_a	C_s	H	h	ϵ_h	t_r	h	B_h	$\triangle$	B_{h_0}
		h	*m*	*sec*	°		*cgs*	*pars*	γ	°	γ	*cgs*	γ	*cgs*
1865	Feb. 26	09	58	804.59	− 0.2	5.00998	0.15805	765	1.030	− 3.1	672	0.15133	−148	0.14985
	26	17	03	804.85	1.4	5.00998	0.15810	771	1.030	− 2.6	685	0.15125	−148	0.14977
	27	09	56	805.55	− 0.3	5.00998	0.15774	746	1.030	− 2.3	664	0.15110	−148	0.14962
	27	17	05	804.94	1.0	5.00998	0.15804	760	1.030	− 1.9	683	0.15121	−148	0.14973
	Mar. 23	09	00	805.80	1.6	5.00998	0.15780	714	1.030	− 1.7	638	0.15142	−148	0.14994
	23	18	10	804.56	− 1.4	5.00998	0.15780	735	1.030	− 1.0	669	0.15111	−148	0.14963
	Apr. 11	10	06	807.67	9.8	5.00998	0.15773	656	1.030	2.6	640	0.15133	−148	0.14985
	11	18	56	805.57	6.6	5.00998	0.15819	710	1.030	2.9	700	0.15119	−148	0.14971
	22	10	01	807.77	9.5	5.00998	0.15762	617	1.030	5.0	636	0.15126	−148	0.14978
	May 22	09	59	809.68	19.6	5.00999	0.15788	544	1.031	10.6	661	0.15127	−148	0.14979
	22	20	33	806.69	14.7	5.00999	0.15846	591	1.031	11.0	707	0.15139	−148	0.14991
	June 12	10	03	807.76	12.1	5.00999	0.15786	535	1.031	10.0	633	0.15153	−148	0.15005
	12	20	46	806.45	11.6	5.00999	0.15832	607	1.031	10.6	717	0.15115	−148	0.14967
	19	10	04	808.62	16.5	5.00999	0.15791	517	1.031	12.2	650	0.15141	−148	0.14993
	19	21	06	807.24	12.7	5.00999	0.15823	558	1.031	12.7	702	0.15121	−148	0.14973
	July 17	10	00	809.54	19.2	5.00999	0.15768	494	1.031	13.7	652	0.15116	−148	0.14968
	17	19	54	806.55	14.0	5.00999	0.15892	582	1.031	13.8	746	0.15146	−148	0.14998
	22	10	08	809.19	21.4	5.00999	0.15817	516	1.031	14.5	689	0.15128	−148	0.14980
	Aug. 3	09	47	819.87	17.2	5.00999	0.15367	196	1.031	12.0	316	0.15051	−170	0.14981
	22	10	00	803.11	14.7	5.00999	0.15800	520	1.031	11.6	644	0.15156	−170	0.14986
	22	19	16	805.90	12.0	5.00999	0.15852	579	1.031	12.0	711	0.15141	−170	0.14971
	Sep. 8	10	04	809.34	14.8	5.00999	0.15754	507	1.031	11.8	634	0.15120	−140	0.14980
	8	18	29	807.37	14.6	5.00999	0.15824	571	1.031	12.2	706	0.15118	−140	0.14978
	14	10	00	808.01	12.2	5.00999	0.15783	541	1.031	11.1	657	0.15126	−140	0.14986
	Oct. 11	10	00	806.62	− 0.2	5.01000	0.15734	584	1.031	5.2	606	0.15128	−140	0.14988
	11	16	55	805.41	0.6	5.01000	0.15784	627	1.031	6.0	663	0.15181	−140	....
	17	10	08	806.64	1.9	5.01000	0.15742	633	1.031	3.3	628	0.15114	−140	0.14974
	17	16	32	805.55	1.6	5.01000	0.15777	651	1.031	4.2	660	0.15117	−140	0.14977
	Nov. 10	10	04	804.98	− 2.1	5.01000	0.15778	674	1.031	1.9	649	0.15129	−140	0.14987
	10	15	39	804.99	− 1.2	5.01000	0.15778	687	1.031	2.3	668	0.15110	−140	0.14970
	12	10	11	805.55	0.0	5.01000	0.15781	669	1.031	1.1	632	0.15149	−140	0.15009
	28	10	00	805.10	− 1.1	5.01000	0.15770	660	1.031	3.6	661	0.15109	−140	0.14969
	28	14	58	804.61	1.6	5.01000	0.15824	688	1.031	3.7	679	0.15145	−140	0.15005
	Dec. 12	10	08	803.79	− 4.2	5.01000	0.15795	704	1.031	1.0	667	0.15128	−140	0.14988
	12	14	40	803.66	− 4.2	5.01000	0.15800	715	1.031	1.1	680	0.15120	−140	0.14980
	18	09	58	803.77	− 1.2	5.01000	0.15832	721	1.031	1.6	694	0.15138	−140	0.14998
	18	14	44	803.89	− 1.2	5.01000	0.15827	716	1.031	1.7	690	0.15137	−140	0.14977
1866	Mar. 19	10	05	806.53	3.0	5.01000	0.15756	679	1.032	− 1.9	599	0.15157	−165	0.14992
	19	18	00	804.99	0.3	5.01000	0.15792	729	1.032	− 1.6	656	0.15136	−165	0.14971
	26	09	57	804.85	0.6	5.01000	0.15823	724	1.032	− 1.6	652	0.15171	−165	0.15006
	26	18	18	803.25	− 0.8	5.01000	0.15841	752	1.032	− 1.0	687	0.15154	−165	0.14989
	Apr. 10	10	00	806.97	6.5	5.01001	0.15770	651	1.032	3.6	651	0.15119	−165	....
	10	19	00	805.73	7.7	5.01001	0.15824	694	1.032	4.0	702	0.15122	−165	....
	18	10	07	807.21	8.7	5.01001	0.15786	635	1.032	4.8	653	0.15133	−165	0.14968
	18	19	12	805.11	2.0	5.01001	0.15808	683	1.032	4.6	689	0.15119	−165	....
	25	10	19	807.75	11.9	5.01001	0.15793	650	1.032	5.6	681	0.15112	−133	0.14979
	25	19	43	805.78	9.5	5.01001	0.15842	667	1.032	6.3	709	0.15133	−133	0.15000
	May 4	10	10	806.45	9.6	5.01001	0.15817	665	1.032	4.8	685	0.15132	−133	0.14999
	4	20	00	804.87	4.0	5.01001	0.15828	711	1.032	5.0	734	0.15094	−133	0.14961
	9	10	00	807.23	14.3	5.01001	0.15823	655	1.032	6.6	702	0.15121	−133	0.14988
	11	10	02	806.31	11.6	5.01001	0.15830	664	1.032	6.2	705	0.15125	−133	0.14992
	11	20	10	806.74	13.7	5.01001	0.15838	694	1.032	6.7	743	0.15095	−133	0.14962
	July 15	10	06	808.78	18.5	5.01001	0.15808	523	1.032	14.4	693	0.15115	−133	0.14982
	15	16	16	808.89	28.0	5.01001	0.15861	593	1.032	14.9	777	0.15084	−133	....
	15	20	32	806.82	16.7	5.01001	0.15877	589	1.032	15.0	774	0.15103	−133	0.14970
	21	10	00	808.63	18.5	5.01001	0.15822	546	1.032	13.7	706	0.15116	−133	0.14983
	21	16	08	808.65	25.9	5.01001	0.15881	581	1.032	14.2	752	0.15129	−133	0.14996
	21	20	58	806.27	19.0	5.01001	0.15903	587	1.032	14.2	758	0.15145	−133	....
	23	16	18	808.39	23.6	5.01001	0.15866	584	1.032	14.4	759	0.15107	−133	0.14974
	23	21	01	806.47	19.6	5.01001	0.15917	603	1.032	14.3	776	0.15141	−133	0.15008
	30	10	00	808.69	21.3	5.01001	0.15844	547	1.032	13.6	696	0.15148	−133	....
	30	16	12	808.45	25.2	5.01001	0.15884	586	1.032	14.0	754	0.15130	−133	0.14997
	30	20	54	807.09	20.2	5.01001	0.15887	586	1.032	14.0	754	0.15133	−133	0.15000
	Oct. 16	14	22	806.37	9.4	5.01002	0.15827	672	1.032	6.4	709	0.15118	−133	0.14985
	16	16	53	805.01	3.6	5.01002	0.15829	680	1.032	6.5	716	0.15115	−133	0.14982
	Nov. 6	09	58	805.34	4.0	5.01002	0.15823	706	1.032	3.4	709	0.15114	−133	0.14981

the abrupt changes in the base-line value, and by means of these the graph of Figure 13-*A* was constructed from group-means as shown in Table 14. The group-means are marked by small circles on the graph.

Period 1876-1930—Table *B* contains data for calculation of the base-line value during 1876-1930. The interval 1891-1919 is based, as above mentioned, on observations made by Geelmuyden with magnetometer Elliott 38. From 1919 to 1927 no observations were made but on February 16, 1927, one was made at Wesöe with magnetometer Elliott 41, which was purchased in 1878. The constants were determined in 1878 at Kew and verified on various occasions. Comparison-observations were made at Rude Skov in 1923 and at Tromsö in 1929. The

TABLE 15

Year	Month	B_{h_0}	No.	Year	Month	B_{h_0}	No.
		cgs				*cgs*	
1882	Aug.	0.15720	2	1903	Nov.	0.15536	6
1891	Aug.	0.15553	5	1905	Oct.	0.15535	3
1891	Sep.	0.15553	7	1907	Mar.	0.15546	4
1891	Nov.	0.15543	5	1908	Aug.	0.15530	4
1896	Aug.	0.15545	6	1910	Feb.	0.15525	4
1897	Sep.	0.15546	4	1912	July	0.15552	6
1899	Feb.	0.15536	4	1915	Jan.	0.15524	6
1900	Sep.	0.15540	6	1918	Aug.	0.15509	6
1902	Oct.	0.15534	4	1927	Feb.	0.15502	2

data for B_{h_0} in Table 15 are arranged in groups consisting of two to seven single values; these are plotted in Figure 13*A*.

The graph for B_{h_0} shows a pronounced fall during 1878-90. A gradual change in the base-line value may be due partly to change in the magnetic moment of the suspended magnet and partly to the torsional moment. The usual form for the base-line is that of an increasing curve corresponding to a decrease in the magnetic moment of the magnet. This increase in B_{h_0} is always comparatively strong in the beginning, while the magnet is new, but diminishes little by little until the curve becomes almost horizontal after a number of years. In this case, however, the graph shows a decreasing course indicating that the decrease in the magnetic moment of the magnet is completely dominated by the influence of change in the torsional moment of the suspension. During 1843-76 the decrease in B_{h_0} is moderate, amounting to only 18γ, that is 0.5γ per year. After the accident there is a fall in the value of B_{h_0} of 235γ during the first three years, which is nearly 150 times as great as before. The magnet probably suffered a momentary loss of magnetism when it fell but this loss may have been gradually regained and consequently a slowly decreasing fall in B_{h_0} might be expected. The dominating cause of the decrease must arise therefore from a decrease in the torsional moment of the suspension. That the decrease is so great can only be explained by supposing that the broken thread was unsatisfactorily mended, and under the influence of the heavy weight of the magnet (13 kg) was gradually lengthened. This would affect the radius

TABLE *B*—*Base-line values, Oslo Observatory, 1882-1927*

Year	Date	H	h	ϵ_h	t_r	c_a	c_λ	h	B_h	$\triangle$	B_h
		cgs	pars	γ	°			γ	cgs	γ	cgs
1882	Jan. 7	0.16053+	478	1.018	11.3	+ 82	+20	589	0.15464	+267	0.157
	Oct. 12	0.16054	469	1.019	7.6	+ 33	+ 7	520	0.15534	+176	0.157
1891	Aug. 20	0.16192 0.16160	750	1.032	13.3	+110	+27	911	0.15281 0.15249	+262	0.155 ....
	27	0.16163 0.16164	740	1.032	12.1	+ 84	+23	871	0.15292 0.15293	+262	0.155 0.155
	Sep. 8	0.16160 0.16159	455	1.032	10.7	+ 74	+19	563	0.15597 0.15596	— 40	0.155 0.155
	9	0.16130 0.16185	440	1.032	10.8	+ 76	+19	549	0.15581 0.15636	— 40	0.155 ....
	18	0.16147 0.16163	460	1.032	10.5	+ 71	+18	564	0.15583 0.15599	— 40	0.155 0.155
	23	0.16132 0.16129	460	1.032	8.5	+ 45	+11	531	0.15601 0.15598	— 40	0.155 0.155
	23	0.16148 0.16132	460	1.032	9.1	+ 52	+13	540	0.15608 0.15592	— 40	0.155 0.155
	Oct. 27	0.16169 0.16142	540	1.033	6.2	+ 15	+ 4	577	0.15592 0.15565	— 17	0.155 0.1554
	Nov. 3	0.16143 0.16118	580	1.033	4.0	— 12	— 3	584	0.15559 0.15534	— 17	0.1554 ....
	3	0.16133 0.16142	580	1.033	4.0	— 12	— 3	584	0.15549 0.15558	— 17	0.1553 0.1554
1896	Aug. 13	0.16303 0.16281	630	1.034	13.8	+118	+29	798	0.15505 0.15483	+ 50	0.1555 0.1553
	13	0.16295 0.16301	630	1.034	13.8	+118	+29	798	0.15497 0.15503	+ 50	0.1554 0.1555
	18	0.16259 0.16270	620	1.034	13.0	+106	+26	773	0.15486 0.15497	+ 50	0.1553 0.1554
1897	July 16	0.16297 0.16285	600	1.034	15.9	+149	+32	801	0.15496 0.15484	+ 50	0.1554 0.1553
	Nov. 9	0.16310 0.16301	845	1.034	3.2	— 22	— 6	846	0.15464 0.15455	+ 95	0.1555 0.1555
1898	Aug. 26	0.16320 0.16319	740	1.034	12.0	+ 92	+23	880	0.15440 0.15439	+ 95	0.1553 0.1553
1899	July 21	0.16333 0.16331*	550	1.034	16.2	+153	+37	759	0.15574 0.15572	— 39	0.1553 0.1553
1900	July 21	0.16323 0.16328	360	1.034	14.2	+123	+30	525	0.15798 0.15803	—270	0.1552 0.1553
	Sep. 1	0.16380 0.16379	410	1.034	13.0	+106	+26	556	0.15824 0.15823	—270	0.15554 0.15553
	Nov. 19	0.16368 0.16369	575	1.034	3.0	— 24	— 7	564	0.15804 0.15805	—270	0.15534 0.15535
1901	Aug. 6	0.16340 0.16344	380	1.034	15.1	+137	+33	563	0.15777 0.15781	—245	0.15532 0.15536

+ = Increased by 20γ according to text.
* = Corrected.

TABLE *B—Base-line values, Oslo Observatory, 1882-1927*—Concluded

Year	Date	H	h	ϵ_h	t_r	c_α	c_λ	h	B_h	$\triangle$	B_{h_0}
		cgs	pars	γ	°			γ	cgs	γ	cgs
1902	June 21	0.16342 0.16400	490	1.034	13.1	+108	+27	641	0.15701 0.15759	−227	.... 0.15532
	23	0.16351 0.16298	445	1.034	12.9	+105	+26	591	0.15760 0.15707	−227	0.15533 ....
1903	Aug. 14	0.16333 0.16366	440	1.034	13.2	+109	+27	591	0.15742 0.15775	−227	0.15515 0.15548
	Nov. 13	0.16364 0.16387	615	1.034	3.9	− 13	− 3	620	0.15744 0.15767	−217	0.15527 0.15550
1904	June 15	0.16405 0.16370	455	1.034	14.7	+131	+32	633	0.15772 0.15737	−217	0.15555 0.15520
1905	Sep. 1	0.16365 0.16377	510	1.034	11.1	+ 80	+20	627	0.15738 0.15750	−207	0.15531 0.15543
	Oct. 4	0.16327 0.16387	605	1.034	6.5	+ 19	+ 5	650	0.15777 0.15737	−207	.... 0.15530
1906	Aug. 3	0.16413 0.16431	450	1.034	16.7	+160	+39	664	0.15749 0.15767	−207	0.15542 0.15560
1907	Aug. 17	0.16375 0.16378	515	1.034	11.5	+ 85	+21	639	0.15736 0.15739	−197	0.15539 0.15542
1908	July 13	0.16394 0.16378	575	1.034	14.0	+121	+30	746	0.15648 0.15632	−110	0.15538 0.15522
	Aug. 7	0.16385 0.16368	560	1.034	14.9	+134	+33	746	0.15639 0.15622	−100	0.15539 0.15522
1909	July 6	0.16352 0.16339	630	1.034	13.6	+115	+28	794	0.15558 0.15545	− 45	0.15513 0.15500
1910	Sep. 9	0.16367 0.16397	705	1.034	11.8	+ 90	+22	841	0.15526 0.15556	+ 3	0.15529 0.15559
1911	July 31	0.16385 0.16370	590	1.034	15.9	+149	+36	795	0.15590 0.15575	− 23	0.15567 0.15552
1912	July 27	0.16377 0.16354	595	1.034	16.2	+154	+37	806	0.15571 0.15548	− 10	0.15561 0.15538
1913	July 12	0.16336 0.16358	220	1.034	13.7	+116	+29	372	0.15964 0.15986	−427	0.15537 0.15559
1914	July 4	0.16302 0.16286	364	1.034	16.0	+150	+33	559	0.15743 0.15727	−192	0.15551 0.15535
1915	July 13	0.16229 0.16199	363	1.034	13.9	+119	+29	523	0.15706 0.15676	−175	0.15531 0.15501
1916	July 27	0.16174 0.16202	288	1.034	16.2	+154	+37	488	0.15686 0.15714	−185	0.15501 0.15529
1917	July 11	0.16160 0.16157	278	1.034	13.5	+115	+28	430	0.15730 0.15727	−190	0.15540 0.15537
1918	Aug. 2	0.16163 0.16150	264	1.034	15.0	+135	+33	441	0.15722 0.15709	−220	0.15502 0.15489
1919	June 23	0.16111 0.16102	256	1.034	12.8	+103	+26	394	0.15717 0.15708	−220	0.15497 0.15488
1927	Feb. 16	0.15975 0.15972	788	1.034	4.0	− 12	− 2	801	0.15174 0.15171	+330	0.15503 0.15501

ρ of the thread and the coefficient of elasticity ϵ, causing a decrease in the torsional moment and consequently increased eye-readings, and thus decreasing values for B_{h_0}.

Abrupt changes in B_{h_0}—To separate the abrupt changes from the gradual movement in the base-line value, we have inserted the last two columns $\triangle$ and B_{h_0} in the Table *B*. The zero-point of the scale in Figure 13*A* is so arranged that the extreme plus and minus corrections are of about the same magnitude, namely, 600γ. A zero-correction is only found during the ten months from December, 1857, to September, 1858. During some months in 1893 and occasionally during 1910-12 there are corrections very near to zero, but the other corrections are of considerable size. Table *B* takes into account those abrupt changes which could be more or less verified by the absolute observations. These corrections, given with opposite sign, are directly applicable as additional corrections to B_{h_0}, as well as to the eye-readings, h.

The horizontal lines are drawn full when the value may be considered more or less satisfactorily fixed, either as based on absolute data or on notes in the observation-books indicating the magnitude of the changes. The vertical lines are drawn full in the cases where the points of time of the changes are more or less certain. In the most uncertain cases, where the corrections are small and their justification doubtful, the lines are dotted. The corrections which are very uncertain have been indicated by asterisks (*).

The three following suggestions are offered to explain the abrupt changes: (*a*) The fixed scale has moved; (*b*) the angle of the mirror, in relation to the magnet, has changed; and (*c*) the magnet has been deflected by sources of local magnetic disturbance. It should be remarked that displacement of the zero-point of the scale has been made intentionally a few times but as the scale is firmly fixed we may assume that an accidental displacement is rare. Any accidental displacement would be quickly noticed by a glance at the plumb-line in front of the scale. Regarding the changes in the base-line value caused by a change in the angle of the mirror mounted on the magnet, the circumstances are much less favorable, especially because the mirror is not satisfactorily fastened in its mounting.

There is no doubt that the majority of the abrupt changes, noted in Table *C*, are accidental and due to unknown changes in the angle of the mirror. In a note, dated February 12, 1855, we find the following remark: "The mirror has been cleaned, because it was fogged." This remark probably explains all the unknown changes during 1843-76, but not those after 1878, because the hall was then heated so that a fogged mirror would be unusual. However accidental changes in the angle of the mirror may have still occurred, for instance, when the glass cover of the bifilar box was cleaned. Various notes are found pertaining to sources of local magnetic disturbances in explanation of some changes, such as installation or removal of iron stoves, iron beds, etc., in the room adjoining the hall, as well as the presence of iron utensils in the house or in the neighborhood.

When Hansteen founded the Oslo Magnetic Observatory in 1841, the site chosen was in a rural district. Today, however, the Observatory

TABLE C—*Complete list of abrupt changes in relation between scale and mirror, Oslo Observatory, 1843-1930*

From		To		Corr. in γ	From		To		Corr. in γ
Year	Day	Year	Day		Year	Day	Year	Day	
1843	Jan. 1	1844	Feb. 23	−125	1892	Oct. 25	1893	Aug. 16	− 2
1844	Feb. 23	1852	Feb. 15	− 10	1893	Aug. 16	1894	Oct. 10	− 27
1852	Feb. 15	1852	Sep. 9	+ 10*	1894	Oct. 10	1895	June 1	− 45*
1852	Sep. 9	1852	Dec. 14	+ 20*	1895	June 1	1895	July 26	− 18*
1852	Dec. 14	1853	Feb. 14	− 5*	1895	July 26	1897	Sep. 13	− 50
1853	Feb. 14	1853	July 27	+ 20*	1897	Sep. 13	1897	Nov. 24	− 95
1853	July 27	1853	Oct. 18	+ 65*	1897	Nov. 24	1898	June 20	− 85*
1853	Oct. 18	1854	May 24	+ 40*	1898	June 20	1898	Sep. 13	− 95*
1854	May 24	1854	July 10	− 10*	1898	Sep. 13	1898	Sep. 29	−120
1854	July 10	1854	Nov. 1	+ 50*	1898	Sep. 29	1898	Oct. 18	−145
1854	Nov. 1	1856	Dec. 8	+ 54	1898	Oct. 18	1899	Apr. 1	+ 45
1856	Dec. 8	1857	Feb. 11	+ 24	1899	Apr. 1	1899	Sep. 5	+ 35
1857	Feb. 11	1857	Dec. 1	+ 11	1899	Sep. 5	1899	Nov. 27	+ 20
1857	Dec. 1	1858	Sep. 26	0	1899	Nov. 27	1900	June 1	+280
1858	Sep. 26	1859	Dec. 19	− 69	1900	June 1	1901	Apr. 21	+270
1859	Dec. 19	1861	Sep. 26	+ 21	1901	Apr. 21	1901	July 1	+255
1861	Sep. 26	1863	June 8	+ 11	1901	July 1	1901	Oct. 6	+245
1863	June 8	1863	July 1	+ 40	1901	Oct. 6	1902	Jan. 20	+240*
1863	July 1	1863	July 20	+ 88	1902	Jan. 20	1902	July 30	+227
1863	July 20	1863	Sep. 9	+108	1902	July 30	1902	Sep. 29	+217
1863	Sep. 9	1864	Mar. 4	+138	1902	Sep. 29	1903	Aug. 25	+227
1864	Mar. 4	1865	Aug. 2	+148	1903	Aug. 25	1903	Oct. 29	+207*
1865	Aug. 2	1865	Aug. 22	+170	1903	Oct. 29	1904	Aug. 15	+217
1865	Aug. 22	1866	Mar. 6	+140	1904	Aug. 15	1905	Aug. 27	+187*
1866	Mar. 6	1866	Apr. 24	+165	1905	Aug. 27	1906	Apr. 14	+207
1866	Apr. 24	1867	Feb. 1	+133	1906	Apr. 14	1906	June 1	+177*
1867	Feb. 1	1869	Nov. 1	+123	1906	June 1	1906	Aug. 10	+207*
1869	Nov. 1	1870	Mar. 6	+105*	1906	Aug. 10	1906	Dec. 1	+197
1870	Mar. 6	1870	Aug. 17	+ 83*	1906	Dec. 1	1907	Aug. 29	+207
1870	Aug. 17	1870	Nov. 21	+105*	1907	Aug. 29	1907	Oct. 7	+187
1870	Nov. 21	1871	June 18	+ 93*	1907	Oct. 7	1907	Oct. 23	+160
1871	June 18	1873	Apr. 15	+408	1907	Oct. 23	1908	July 30	+110
1873	Apr. 15	1873	June 18	+458*	1908	July 30	1908	Oct. 4	+100
1873	June 18	1873	Aug. 6	+403*	1908	Oct. 4	1909	Sep. 2	+ 45
1873	Aug. 6	1876	Aug. 1	+440	1909	Sep. 2	1909	Sep. 26	+ 15*
1876	Aug. 1	....	....	+610	1909	Sep. 26	1910	Sep. 2	+ 35
					1910	Sep. 2	1910	Dec. 19	+ 3*
1878	Feb. 16	1878	July 23	−489	1910	Dec. 19	1911	Feb. 8	+ 23
1878	July 23	1878	July 31	−500*	1911	Feb. 8	1911	Apr. 21	+ 3*
1878	July 31	1878	Nov. 29	−544*	1911	Apr. 21	1911	Sep. 21	+ 23
1878	Nov. 29	1879	June 5	−515*	1911	Sep. 21	1912	Apr. 14	+ 3*
1879	June 5	1882	June 3	−533	1912	Apr. 14	1912	Sep. 19	+ 10
					1912	Sep. 19	1912	Oct. 25	+ 3
1882	June 3	1882	Sep. 6	−267	1912	Oct. 25	1913	Jan. 21	+ 23
1882	Sep. 6	1882	Oct. 3	−502	1913	Jan. 21	1913	Mar. 24	+407
1882	Oct. 3	1883	Oct. 3	−176	1913	Mar. 24	1913	Oct. 22	+427
1883	Oct. 3	1884	Apr. 14	−172*	1913	Oct. 22	1913	Nov. 9	+397*
1884	Apr. 14	1885	Oct. 7	−160	1913	Nov. 9	1913	Dec. 25	+367*
1885	Oct. 7	1886	Jan. 2	−175*	1913	Dec. 25	1914	Feb. 27	+382*
1886	Jan. 2	1886	Nov. 30	−160	1914	Feb. 27	1914	Apr. 25	+392
1886	Nov. 30	1887	Nov. 29	−143*	1914	Apr. 25	1914	July 17	+192
1887	Nov. 29	1888	Sep. 6	−132*	1914	July 17	1914	Oct. 6	+182
1888	Sep. 6	1889	Oct. 4	−141	1914	Oct. 6	1914	Nov. 19	+152
1889	Oct. 4	1889	Oct. 11	−186	1914	Nov. 19	1915	Jan. 15	+105
1889	Oct. 11	1890	June 6	−238	1915	Jan. 15	1915	Feb. 28	+135
1890	June 6	1890	Aug. 1	−265*	1915	Feb. 28	1915	May 16	+155
1890	Aug. 1	1891	Jan. 13	−386*	1915	May 16	1916	Jan. 2	+175
1891	Jan. 13	1891	Aug. 27	−262	1916	Jan. 2	1916	Feb. 8	+145*
1891	Aug. 27	1891	Oct. 10	+ 40	1916	Feb. 8	1916	Apr. 25	+175
1891	Oct. 10	1892	Mar. 17	+ 17	1916	Apr. 25	1916	Oct. 18	+185
1892	Mar. 17	1892	Aug. 27	+ 37*	1916	Oct. 18	1916	Dec. 3	+170*
1892	Aug. 27	1892	Oct. 25	+ 27*	1916	Dec. 3	1917	Jan. 4	+150*

New telescope mounted July 1, 1863.
Suspension thread broken by accident August 6, 1873.
* = Uncertain values.

TABLE C—*Complete list of abrupt changes in relation between scale and mirror, Oslo Observatory, 1843-1930*—Concluded

From		To		Corr. in γ	From		To		Corr. in γ
Year	Day	Year	Day		Year	Day	Year	Day	
1917	Jan. 4	1917	May 10	+170*	1921	Nov. 1	1922	Apr. 23	+210*
1917	May 10	1917	Sep. 13	+190	1922	Apr. 23	1923	May 28	+230
1917	Sep. 13	1918	Apr. 18	+185	1923	May 28	1923	Aug. 13	+235*
1918	Apr. 18	1918	June 17	+165	1923	Aug. 13	1924	Feb. 10	+215*
1918	June 17	1919	Jan. 3	+220	1924	Feb. 10	1924	Apr. 5	+220
1919	Jan. 3	1919	Mar. 28	+235*	1924	Apr. 5	1925	Apr. 9	+270
1919	Mar. 28	1919	Oct. 15	+220	1925	Apr. 9	1925	June 6	+215*
1919	Oct. 15	1919	Nov. 12	+250	1925	June 6	1926	Sep. 3	+240
1919	Nov. 12	1920	Jan. 10	+295	1926	Sep. 3	1926	Nov. 29	−330
1920	Jan. 10	1920	Apr. 4	+230	1926	Nov. 29	1927	Jan. 29	−320*
1920	Apr. 4	1920	May 28	+250	1927	Jan. 29	1928	May 27	−330
1920	May 28	1920	June 29	+280	1928	May 27	1928	Oct. 6	−315*
1920	June 29	1920	Oct. 15	+250	1928	Oct. 6	1928	Oct. 27	−340*
1920	Oct. 15	1920	Dec. 5	+230	1928	Oct. 27	1929	Jan. 5	−380*
1920	Dec. 5	1921	Jan. 25	+260*	1929	Jan. 5	1929	May 22	−355*
1921	Jan. 25	1921	Mar. 5	+280	1929	May 22	1929	Aug. 23	−310*
1921	Mar. 5	1921	Apr. 29	+255*	1929	Aug. 23	1930	May 5	−365*
1921	Apr. 29	1921	June 9	+270*	1930	May 5	1930	May 29	−325*
1921	June 9	1921	July 23	+290	1930	May 29	1930	June 24	−295*
1921	July 23	1921	Sep. 30	+220	1930	June 24	1930	Oct. 13	−325*
1921	Sep. 30	1921	Nov. 1	+190	1930	Oct. 13	1931	Jan. 31	−375*

* =Uncertain values.

is surrounded by a modern city with houses and streets with electric cables, tramways, etc. Up to 1930 it still stood in an old park. Figure 14 shows the situation in 1927, before the park itself was divided into house-lots even in the immediate vicinity of the Observatory.

No serious change in the situation seems to have developed until May 3, 1894, when the first near-by electric tramway was opened at the northwest border of the map. As to the tramway south of the Observatory, Part I was opened in 1906 and Part II in 1911. Apparently the tramway did not exert any noticeable effect, either on the bifilar readings or on the absolute measurements. Cables for light and power are shown on the map; all the cables carry alternating current. Water-pipes should be mentioned also.

The pier for the absolute magnetic observations stands in the park north of the Observatory at the point marked *P*. The large building at the northern corner of the park, the University Library, marked *U.L.*, containing much steel, was completed in 1913, but does not appear to have caused any marked disturbance. However, the observations made after 1917 seem to be about 20γ lower than might be expected. Despite this the observations are given without alteration but a comparison with the final base-line value will show the situation.

The most probable cause of disturbance is no doubt the little building south of the library designated *T* on the map. It houses an electric transformer-station, constructed during the summer of 1915 and opened for continuous service November 21 of that year. We have concluded

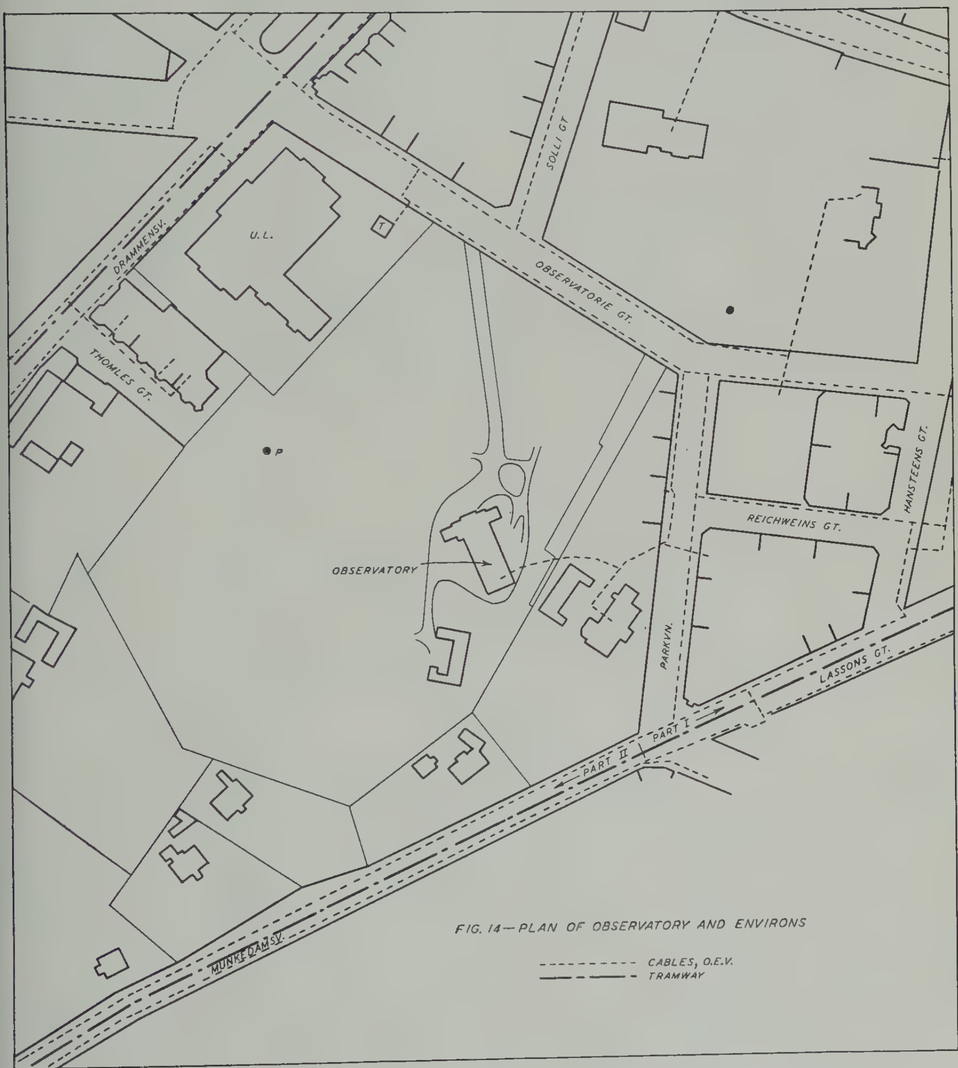


FIG. 14—PLAN OF OBSERVATORY AND ENVIRONS

that a local electromagnetic field was brought into play during the summer of 1915. Whether the supposed electromagnetic field affects the bifilar readings is difficult to say, but there seems, after 1915, to be a change in the character of the abrupt changes in the base-line value (see Fig. 13*A*).

Summary—From what has been said above, it is clear that the many abrupt changes in the base-line values represent the weakest point in the results of the reduction of the magnetic material left by Hansteen, because all the changes in B_h between two breaks, where the value is

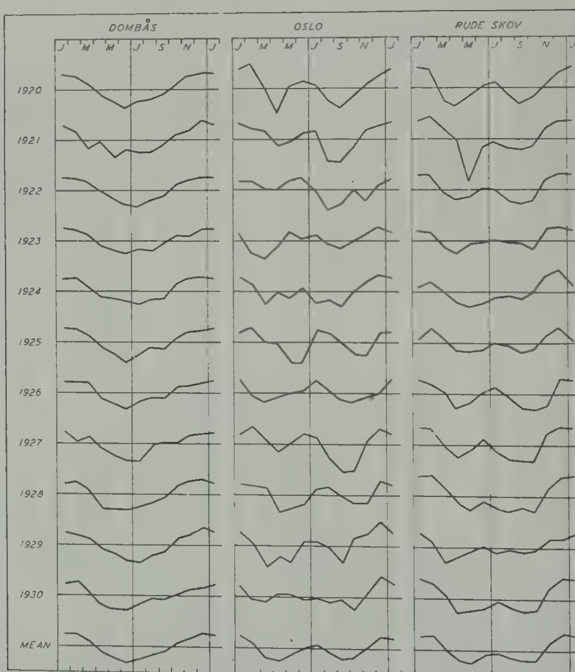


FIG. 15—COMPARISON OF ANNUAL VARIATION IN H AT 9^h, DOMBÅS, OSLO, AND RUDE SKOV, 1920-30 (DOMBÅS DATA BASED ONLY ON STRICTLY QUIET VALUES)
VERTICAL SCALE IN GAMMAS 0 20 40

based on absolute observations, must be estimated. The procedure used was as follows:

Starting with one of the breaks, where B_h was determined by absolute observations, the reduction was continued beyond the break using the same value for B_h until a decided jump was reached. If the size of the jump was noted in the observation-book, B_h was changed accordingly, but if the jump was not described it was necessary to estimate as well as possible its magnitude. When the reduction had reached the next break where again B_h was determined by absolute observations, there

should be agreement between the base-line value used for the preceding interval and that for the new break. If this was the case, the procedure was provisionally accepted as satisfactory. In many cases agreement was not so obtained and it was necessary to seek causes for intermediate changes and to estimate corrections such that the sum of the corrections would correspond to the total difference between the base-line values of the two breaks in question, where B_h could be considered more or less safely based on absolute observations.

The method used will be understood by a glance at the curve for such corrections appearing in the lower part of Figure 16. In deciding on the distribution of the corrections in B_h it was found helpful to consider the typical annual variation in H at 09^h as shown in Figure 15 for the epoch 1920-30. The graphs of differences between annual and monthly means corrected for secular variation often showed the annual variation to differ so much from the average that it furnished a hint as to the distribution of the corrections. The marked 11-year period, corresponding to the variation in sunspot-frequency was also helpful. In Figure 15 the Dombås graphs represent strictly quiet values while the monthly data for Oslo and Rude Skov are based on all days. Extremely high and low data are excluded in the computation of monthly means even at Oslo and Rude Skov (see below).

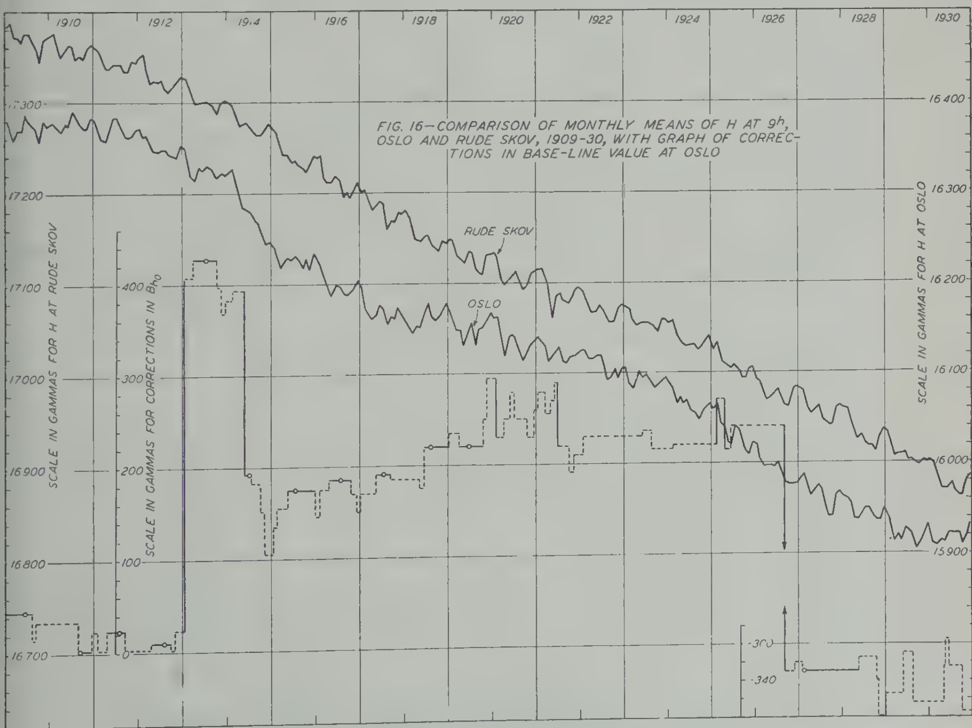


FIG. 16—COMPARISON OF MONTHLY MEANS OF H AT 9^h, OSLO AND RUDE SKOV, 1909-30, WITH GRAPH OF CORRECTIONS IN BASE-LINE VALUE AT OSLO

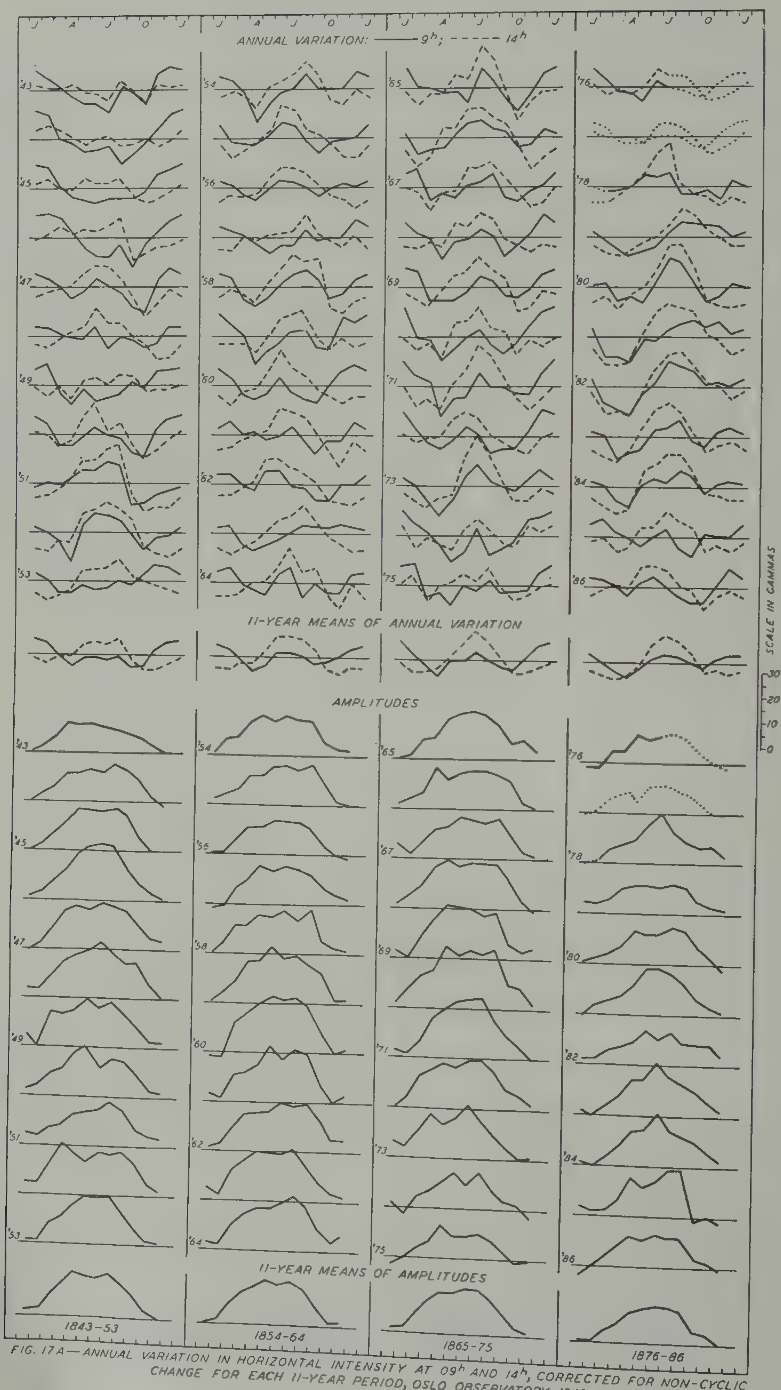


FIG. 17A—ANNUAL VARIATION IN HORIZONTAL INTENSITY AT 09h AND 14h, CORRECTED FOR NON-CYCLIC CHANGE FOR EACH 11-YEAR PERIOD, OSLO OBSERVATORY, 1843-86

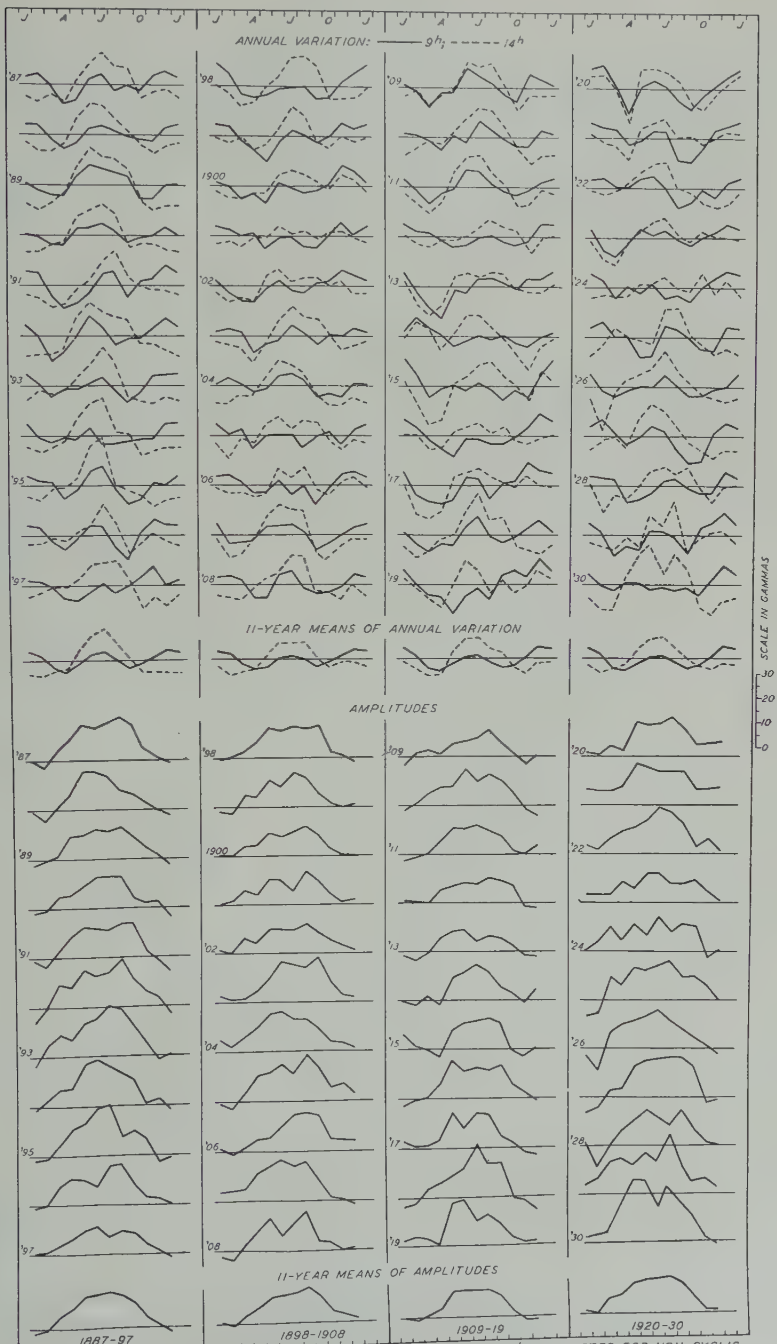


FIG. 17 B—ANNUAL VARIATION IN HORIZONTAL INTENSITY AT 09^h AND 14^h, CORRECTED FOR NON-CYCLIC CHANGE FOR EACH 11-YEAR PERIOD, OSLO OBSERVATORY, 1887-1930

Besides the curves for the annual variation, given in Figure 16, Figures 17*A* and 17*B* show the annual variations in H for 09^h, and 14^h, as well as the annual variation of the amplitude represented by the difference between the values for these two hours. In Figure 16 are plotted the final monthly mean values for H at Oslo for 09^h during the epoch 1909-30. For comparison we have added a corresponding graph for 09^h at Rude Skov. The graph at the bottom gives the graph for the correction in B_h for Oslo, which justifies the various corrections. Small circles indicate the absolute observations.

Results of the final reduction of the bifilar readings

We have described in the preceding pages the procedures adopted for determining the values of the necessary constants for the final reduction of the bifilar readings. As an example of a complete reduction of the eye-readings let us consider the detailed observations of Table 1 for 09^h on June 3, 1863. The mean reading was 670.7 pars at 8°.7 R. The following constants are taken from the various tables and graphs: Scale-value, $\epsilon_h = 1.029$; temperature-coefficients, $a(t-t_0)+s(t-t_0)^2 = c_a = 47.1$ and $\lambda(t-t_0) = c_\lambda = 11.1$ for $a = 12.3\times10^{-5}$, $\lambda = 3.0\times10^{-5}$, $s = 0.12\times10^{-5}$, and $t_0 = 5°.0$ R; and we get $H = h + c_a + c_\lambda + B_h + \triangle = 690 + 47 + 11 + 14989 + 11 = 15748\gamma$, which is the value for 09^h, June 3, 1863.

All eye-readings for 09^h and for 14^h were compiled in this way. The reduced monthly mean values are entered in Table *D*. In computing the monthly means the extremely high and low readings were excluded, since these are liable, because of their preponderating influence, to give a misleading value for the average. It is difficult to adopt a criterion for rejections; it was decided that values 50γ above or below the average of the rest of the values in any month should be excluded. Values involving such rejections are indicated by parentheses. Occasionally tabulated values are followed by an asterisk to indicate they are from interpolated data and are used when calculating monthly means. Monthly mean values at 09^h and 14^h and annual means for the entire period 1843-1930 are given in Table *D*, while Table *E* gives the monthly mean differences between values at 14^h and 09^h.

Finally, monthly mean values of H at Oslo for 09^h for the entire period 1843-1930 are plotted in Figure 18. It affords a good general idea of the secular variation, which in its real form is represented by the broken line. It shows that H at Oslo has been increasing at an average rate of about 13γ annually during 1843-1900, while during 1910-30 it has been decreasing at an average annual rate of about 22γ. The highest point in the secular variation may be placed about 1906.

The curve, represented by the monthly mean values, oscillates above and below the graph for real secular movement so that the difference between the two curves shows well the 11-year period. Yearly mean data for this 11-year period ($\triangle H$) are compared with the annual mean values of Wolfer's relative sunspot-numbers in the inset on Figure 18. On the whole there is a striking parallelism between the two curves, even in detail, but it may be questionable whether this high degree of parallelism is real, because it seems strange that there should be hardly

TABLE D—*Monthly and annual mean values for H at 09ʰ and 14ʰ, Oslo Observatory, 1843-1930*

Values at 09ʰ

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.	Mean
						H=15000+							γ
1843	497	494	488	482	480	481	479	502	499	494	520	527	15495
1844	529	526	507	502	495	497	500	486	492	503	514	525	15506
1845	529	526	509	499	495	493	494	493	483	495	509	513	15503
1846	515	517	515	504	493	487	488	499	482	504	514	524	15504
1847	531	526	514	504	507	516	508	500	485	479	502	511	15507
1848	505	504	501	498	498	509	492	502	499	494	499	513	15501
1849	514	521	503	496	511	507	512	520	532	532	550	555	15521
1850	560	554	536	538	546	553	548	546	533	532	553	564	15547
1851	566	569	567	573	581	581	589	586	553	555	564	566	15571
1852	570	571	567	552	586	599	602	603	594	585	599	604	15586
1853	614	612	601	602	610	608	611	618	617	628	636	636	15616
1854	633	633	625	604	620	631	638	653	644	644	648	663	15636
1855	661	648	648	649	657	570	669	658	650	660	664	667	15658
1856	679	678	670	667	678	685	685	682	676	683	687	686	15680
1857	691	688	685	678	670	677	677	691	682	685	586	700	15684
1858	695	692	673	667	674	685	692	695	687	671	675	685	15683
1859	688	681	673	650	662	669	681	683	670	668	697	693	15676
1860	704	696	681	678	681	695	682	675	673	687	698	702	15688
1861	699	708	700	705	702	709	720	713	704	718	722	741	15712
1862	739	740	733	729	747	749	737	737	728	728	743	745	15738
1863	754	757	742	739	744	750	758	764	765	765	769	767	15756
1864	767	773	763	762	762	779	791	768	783	780	783	802	15775
1865	806	792	790	787	788	780	806	796	782	773	787	803	15791
1866	807	792	799	808	819	832	837	834	835	825	831	846	15822
1867	847	851	826	832	829	839	843	850	831	829	837	843	15838
1868	853	845	842	825	839	842	850	847	830	840	850	866	15844
1869	860	858	832	831	831	836	846	842	829	827	833	843	15839
1870	847	825	825	809	820	831	840	827	823	833	849	861	15833
1871	867	854	854	827	844	849	871	862	865	862	864	883	15858
1872	896	883	872	869	878	890	883	869	873	875	889	908	15882
1873	907	905	894	886	903	926	938	927	927	927	938	949	15919
1874	945	938	934	926	915	927	948	930	938	945	966	972	15939
1875	978	980	953	957	949	964	960	968	959	960	970	977	15965
						H=16000+							
1876	−17	−23	−31	−30	−35	−16	−20	−20*	−22*	−20*	−08*	001*	15980
1877	007*	002*	−08*	−11*	−09*	−06*	−04*	−06*	−13*	−13*	−03*	004*	15995*
1878	012*	010*	010	013	024	024	027	010	012	014	009	025	16016
1879	020	015	010	007	010	016	028	039	038	039	039	033	16024
1880	037	038	023	025	019	036	054	049	033	017	021	029	16032
1881	027	006	005	003	023	023	032	037	042	038	042	033	16026
1882	039	020	017	013	028	038	060	057	053	043	044	043	16038
1883	049	048	031	035	050	058	060	068	052	048	061	066	16052
1884	063	063	052	049	069	075	074	087	083	071	081	085	16071
1885	086	094	086	085	080	091	100	087	083	104	107	108	16093
1886	121	119	115	107	118	125	116	110	105	107	122	135	16117
1887	129	134	128	116	124	141	149	138	146	144	159	166	16140
1888	164	164	153	146	151	162	164	162	157	155	156	165	16158
1889	168	163	161	157	177	187	183	182	179	162	164	175	16172
1890	177	173	165	165	175	174	176	168	157	160	160	164	16168
1891	157	158	139	130	135	144	160	163	142	156	160	171	16151
1892	167	157	139	145	159	176	167	153	159	159	166	175	16160
1893	169	163	155	163	165	171	178	171	162	172	187	190	16170
1894	193	183	181	185	186	197	199	187	190	194	196	210	16192
1895	211	209	210	201	209	224	233	224	215	221	235	236	16219
1896	245	247	240	238	250	264	268	255	250	275	291	290	16259
1897	294	296	295	290	292	301	310	307	293	279	295	288	16295
1898	298	293	281	281	286	299	314	318	312	310	316	327	16303
1899	338	336	324	318	309	326	335	332	326	330	342	338	16330
1900	341	340	333	340	334	354	354	351	355	363	382	380	16352
1901	374	373	369	371	359	368	370	358	359	374	384	376	16370
1902	374	370	362	362	372	378	370	370	374	377	386	380	16373

* = Interpolated values.

Table D—*Monthly and annual mean values for H at 09ʰ and 14ʰ, Oslo Observatory, 1843-1930*—Continued

Values at 09ʰ

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.	Mean
						$H=16000+$							γ
1903	377	379	377	361	368	372	384	379	369	377	377	383	16375
1904	380	385	380	373	375	384	387	381	366	369	366	376	16377
1905	375	368	374	359	373	376	377	369	380	386	379	396	16376
1906	399	399	393	383	383	391	378	384	368	381	391	391	16387
1907	387	371	372	375	385	387	387	383	368	371	386	392	16380
1908	395	395	380	374	373	391	392	380	375	372	373	381	16382
1909	378	373	358	370	369	388	380	375	366	357	380	374	16372
1910	376	378	373	367	378	373	391	384	376	371	371	383	16377
1911	381	370	359	357	370	384	382	372	364	361	363	369	16369
1912	371	363	361	353	347	346	349	349	343	342	340	353	16351
1913	351	334	318	314	328	325	331	328	324	317	322	320	16326
1914	322	328	313	302	286	282	280	271	268	255	245	246	16283
1915	243	235	218	225	229	226	231	227	218	228	217	235	16228
1916	228	220	206	197	187	199	197	190	188	190	195	204	16200
1917	196	174	166	161	165	177	173	155	164	161	174	165	16169
1918	160	151	145	153	152	167	179	163	159	163	171	178	16162
1919	170	157	149	149	132	148	156	132	150	150	158	168	16152
						$H=15500+$							
1920	662	663	644	620	641	643	639	625	615	623	632	637	16137
1921	641	637	630	614	618	625	630	613	613	618	619	623	16123
1922	626	626	617	616	620	620	610	592	595	605	595	606	16111
1923	607	590	583	591	602	595	598	589	583	588	591	596	16093
1924	591	583	566	573	566	570	558	556	548	557	563	565	16066
1925	560	564	545	542	523	520	542	537	525	513	509	523	16035
1926	520	503	496	497	497	495	501	490	379	476	476	477	15992
1927	483	487	474	464	468	475	470	452	440	440	465	468	15965
1928	463	461	457	437	437	442	450	450	442	436	436	450	15947
1929	444	434	413	420	414	428	425	419	404	422	424	431	15923
1930	420	410	408	414	412	422	422	421	422	411	419	433	15918

Values at 14ʰ

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.	Mean
						$H=15000+$							
1843	498	499	501	506	503	504	499	521	514	506	525	527	15509
1844	530	533	520	525	518	522	524	516	517	521	516	521	15522
1845	529	531	523	521	529	525	526	527	511	507	509	513	15521
1846	519	523	531	527	531	530	534	544	508	517	521	525	15527
1847	530	532	532	535	542	548	546	536	517	500	511	519	15529
1848	513	512	520	527	533	548	537	538	527	523	511	514	15525
1849	525	519	531	523	541	548	545	557	560	551	555	559	15543
1850	565	563	555	560	581	594	572	578	561	551	558	568	15568
1851	576	577	583	591	608	609	618	623	583	569	573	573	15590
1852	580	581	592	595	621	627	637	636	630	612	609	608	15611
1853	617	614	618	624	643	647	649	658	645	642	640	638	15636
1854	636	646	641	632	653	660	670	682	672	655	654	668	15656
1855	666	656	663	673	682	702	701	687	683	678	668	668	15677
1856	680	680	685	689	702	712	711	708	697	691	688	684	15694
1857	688	687	698	697	701	703	707	719	705	698	694	705	15700
1858	695	701	696	690	705	716	727	722	724	683	679	687	15702
1859	690	690	691	684	697	715	717	722	701	693	701	697	15700
1860	701	692	705	708	721	740	726	720	710	705	699	705	15711
1861	706	711	722	728	734	755	755	756	744	734	723	747	15735
1862	743	746	752	759	778	781	776	774	767	755	754	755	15762
1863	765	762	767	773	784	789	797	806	793	781	776	772	15780
1864	773	777	785	792	796	813	830	813	820	798	792	816	15800
1865	806	795	806	805	820	818	845	834	808	785	803	810	15811
1866	811	801	813	841	842	862	868	865	863	849	835	847	15841
1867	859	854	840	855	855	873	874	879	764	851	843	846	15858
1868	857	855	861	858	879	876	887	884	867	864	859	865	15868
1869	865	859	852	862	874	877	887	877	867	839	840	852	15863
1870	850	842	850	839	870	874	887	870	870	852	866	865	15861
1871	873	858	867	858	882	894	918	912	897	881	874	884	15883

TABLE D—*Monthly and annual mean values for H at 09h and 14h, Oslo Observatory, 1843-1930*—Concluded

Values at 14h

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.	Mean
						$H=15000+$							γ
1872	896	891	897	899	915	923	921	909	904	891	900	912	15905
1873	920	914	913	922	929	959	982	958	945	937	938	950	15939
1874	949	932	943	940	937	956	967	960	951	952	970	967	15952
1875	974	980	961	971	976	983	978	989	975	967	996	976	15975
						$H=16000+$							
1876	−20	−26	−21	−21	−13	003	001*	003*	−04*	−13*	−07*	−02*	15990
1877	007*	004*	003*	004*	000*	014*	017*	014*	003*	−06*	−02*	004*	16005*
1878	012*	013*	021	028	043	057	068	034	029	028	023	031	16032
1879	029	024	022	027	034	040	050	063	059	049	044	037	16040
1880	038	043	032	041	047	060	079	079	060	031	027	025	16047
1881	026	014	016	019	046	061	070	070	067	051	049	037	16044
1882	043	026	029	027	047	066	081	084	072	061	061	052	16054
1883	058	051	049	057	078	093	099	093	076	061	067	071	16071
1884	066	063	060	065	098	104	116	118	107	091	093	090	16089
1885	094	098	091	096	112	115	129	124	121	101	107	105	16108
1886	113	119	124	124	142	145	141	133	129	115	127	133	16129
1887	129	128	136	133	152	168	179	173	175	153	161	165	16154
1888	162	155	155	161	182	193	192	179	170	160	155	160	16169
1889	163	161	166	176	197	212	206	207	198	172	168	171	16183
1890	173	172	175	176	195	199	202	194	165	165	165	157	16178
1891	156	153	145	147	160	168	183	190	171	161	160	159	16163
1892	155	156	158	163	190	202	196	192	180	171	172	168	16175
1893	163	173	173	178	191	203	219	210	184	183	184	191	16188
1894	190	188	193	199	220	233	231	213	211	196	201	206	16207
1895	208	208	219	224	236	263	274	238	236	234	229	235	16234
1896	242	247	256	258	270	279	300	289	269	281	295	291	16273
1897	294	298	303	302	310	322	323	326	311	287	298	285	16305
1898	297	294	286	293	310	321	338	342	338	315	319	323	16315
1899	335	332	335	327	332	343	364	356	337	333	342	340	16340
1900	342	341	341	349	353	370	374	375	372	369	383	381	16362
1901	375	376	381	379	380	388	382	384	379	385	386	381	16381
1902	377	370	374	371	392	398	389	393	393	389	392	383	16385
1903	383	381	380	369	386	405	415	407	407	394	383	387	16391
1904	390	390	393	393	406	418	414	406	385	377	375	379	16394
1905	373	363	382	380	397	406	399	407	408	397	393	402	16392
1906	402	397	397	393	394	414	407	414	396	390	401	403	16401
1907	394	379	381	396	412	420	415	415	382	374	387	390	16395
1908	390	387	385	391	398	402	413	411	382	379	373	383	16391
1909	372	376	363	373	380	400	396	398	378	361	375	375	16379
1910	374	381	385	383	395	404	411	410	398	382	369	375	16389
1911	376	368	361	368	392	405	405	391	380	364	365	377	16379
1912	373	365	361	364	362	363	366	370	362	357	337	350	16361
1913	348	327	317	325	345	344	339	341	336	322	319	317	16332
1914	322	325	317	299	306	305	309	294	278	261	243	256	16294
1915	257	237	217	219	245	247	254	253	239	228	213	236	16237
1916	223	220	208	208	219	221	222	213	216	202	199	202	16213
1917	202	176	169	169	194	192	202	182	173	166	170	159	16180
1918	154	147	154	165	171	192	208	187	191	170	169	166	16173
1919	175	165	156	150	167	187	176	158	168	158	161	172	16166
						$H=15500+$							
1920	665	665	652	624	669	668	665	656	637	632	642	648	16152
1921	654	648	642	629	652	656	657	640	639	631	633	636	16143
1922	633	630	630	636	642	647	648	626	620	611	606	607	16128
1923	614	597	590	608	615	618	621	605	598	605	599	596	16106
1924	592	591	586	583	587	584	586	574	567	577	557	565	16079
1925	547	552	564	554	549	543	569	569	543	531	521	523	16047
1926	514	484	510	518	520	521	531	512	496	485	479	472	16004
1927	470	479	480	471	494	505	501	485	473	465	460	466	15979
1928	465	442	455	450	457	470	473	466	471	452	438	450	15957
1929	451	446	440	449	438	463	452	468	425	432	436	436	15945
1930	424	416	417	444	463	473	450	466	456	425	421	430	15940

* = Interpolated values.

Table E Difference in γ between 14^h and 09^h for monthly mean values in H, Oslo Observatory, 1843-1930

Year	J	F	M	A	M	J	J	A	S	O	N	D	Mean
1843	1	5	13	24	23	23	20	19	15	12	5	0	13
1844	1	7	13	23	23	25	24	30	25	18	2	−4	17
1845	0	5	14	22	34	32	32	34	28	12	0	0	18
1846	4	6	16	23	38	43	46	45	26	13	7	1	23
1847	−1	6	18	31	35	32	38	36	32	21	9	8	22
1848	8	8	19	29	35	39	45	36	28	29	12	1	24
1849	11	−2	28	27	30	41	33	37	28	19	5	4	22
1850	5	9	19	22	35	41	24	32	28	19	5	4	20
1851	10	8	16	18	27	28	29	37	30	14	9	7	19
1852	10	10	25	43	35	28	35	33	36	27	10	4	25
1853	3	2	17	22	33	39	38	40	28	14	4	2	20
Mean	5	6	18	26	32	34	33	34	28	18	6	2	20
1854	3	13	16	28	33	29	32	29	28	11	6	5	20
1855	5	8	15	24	25	32	32	29	33	18	4	1	19
1856	1	2	15	22	24	27	26	26	21	8	1	−2	14
1857	−3	−1	14	19	31	26	30	28	23	13	8	5	16
1858	0	9	23	23	31	31	35	27	37	12	4	2	19
1859	2	9	18	34	35	46	36	39	31	25	4	4	24
1860	−3	−4	24	30	40	45	44	45	37	18	1	3	23
1861	7	3	22	23	32	46	35	43	40	16	1	6	23
1862	4	6	19	30	31	32	39	37	39	27	11	10	24
1863	11	5	25	34	40	39	39	42	28	16	7	5	24
1864	6	4	22	30	34	34	39	45	37	18	9	14	24
Mean	3	5	19	27	32	35	35	35	32	17	5	5	21

Year	J	F	M	A	M	J	J	A	S	O	N	D	Mean
1865	0	3	16	18	32	38	39	38	26	12	16	7	20
1866	4	9	14	33	23	30	31	31	28	24	4	1	19
1867	12	3	14	23	26	34	31	29	33	22	6	3	20
1868	4	10	19	33	40	34	37	37	37	24	9	−1	24
1869	5	1	20	31	43	41	41	35	38	12	7	9	24
1870	3	17	25	30	50	43	47	43	47	19	17	4	28
1871	6	4	13	31	38	45	47	50	32	19	10	1	25
1872	0	8	25	30	37	33	38	40	31	16	11	4	23
1873	13	9	19	36	26	33	44	31	18	10	0	1	20
1874	4	−6	9	14	22	29	19	30	13	7	4	−5	13
1875	−4	0	8	14	27	19	18	21	16	.7	−1	−1	10
Mean	4	5	17	27	33	34	36	35	29	16	8	2	21
1876	−3	−3	10	9	22	19	21*	23*	18*	7*	1*	3*	10
1877	0*	2*	11*	15*	9*	20*	21*	20*	16*	7*	1*	0*	10
1878	0*	3*	11	15	19	33	41	24	17	14	14	6	17
1879	9	9	12	20	24	24	22	24	21	10	5	4	15
1880	1	5	9	16	28	24	25	30	27	14	6	−4	15
1881	−1	8	11	16	23	38	38	33	25	13	7	4	18
1882	4	6	12	14	19	28	21	27	19	18	17	9	16
1883	9	3	18	22	28	35	39	25	24	13	6	5	19
1884	3	0	8	16	29	29	42	31	24	20	12	5	18
1885	8	4	5	11	32	24	29	37	38	−3	0	−3	15
1886	−8	0	9	17	24	20	25	23	24	8	5	−2	12
Mean	2	3	11	16	23	27	30	27	23	11	7	2	15

* = Interpolated values.

TABLE E—*Difference in γ between 14ʰ and 09ʰ for monthly mean values in H, Oslo Observatory, 1843-1930*—Concluded

Year	J	F	M	A	M	J	J	A	S	O	N	D	Mean
1887	0	−6	8	17	28	27	30	35	29	9	2	−1	14
1888	−2	−9	2	15	31	31	28	17	13	5	−1	−5	11
1889	−5	−2	5	19	20	25	23	25	19	10	4	−4	9
1890	−4	−1	10	11	20	25	26	26	8	5	5	−7	10
1891	−1	−5	6	17	25	24	23	27	28	5	0	−12	12
1892	−12	−1	19	18	31	26	29	39	21	12	6	−7	15
1893	−6	10	18	15	26	32	41	39	22	11	−3	1	18
1894	−3	5	12	14	34	36	32	26	21	2	5	−4	15
1895	−3	−1	9	23	27	39	41	14	21	13	−6	−1	15
1896	−3	0	16	20	20	15	32	34	19	6	4	1	14
1897	0	2	8	12	18	21	13	19	18	8	3	−3	10
Mean	−4	−1	10	16	25	27	29	27	20	8	2	−4	13
1898	−1	1	5	12	24	22	24	24	26	5	3	−4	12
1899	−3	−4	11	9	23	17	29	24	11	3	0	2	10
1900	1	1	8	9	19	16	20	24	17	6	1	1	10
1901	1	3	12	8	21	20	12	26	20	11	2	5	11
1902	3	0	12	9	20	20	19	23	19	12	6	3	12
1903	6	2	3	8	18	33	31	28	38	17	6	4	16
1904	10	5	13	20	31	34	27	25	19	8	9	3	17
1905	−2	−5	8	21	24	30	22	38	28	11	14	6	16
1906	3	2	4	10	11	23	29	30	28	9	10	12	14
1907	7	8	9	21	27	33	28	32	14	3	1	−2	15
1908	5	8	5	17	25	11	21	31	7	7	0	2	9
Mean	2	0	8	13	22	24	25	28	21	9	5	3	13

Year	J	F	M	A	M	J	J	A	S	O	N	D	Mean
1909	−6	3	5	3	11	12	16	23	12	4	−5	1	7
1910	−3	3	12	16	17	31	20	26	22	11	−3	−8	12
1911	−5	−2	2	11	22	21	23	19	16	3	2	8	10
1912	2	2	0	11	15	17	17	21	19	15	−3	−3	10
1913	−3	−7	−1	11	17	19	8	13	12	5	−3	−3	6
1914	0	−3	4	−3	20	23	29	23	10	6	−2	10	11
1915	14	2	−1	−6	16	21	23	26	21	0	−4	1	9
1916	−5	0	2	11	32	22	25	23	28	12	4	−2	13
1917	6	2	3	8	29	15	29	27	9	5	−4	−6	10
1918	−6	−4	9	12	19	25	45	28	28	−1	−2	−12	12
1919	5	8	7	1	35	39	20	26	18	8	3	4	14
Mean	0	0	4	6	21	22	23	23	18	6	−2	−1	10
1920	3	2	8	4	28	25	26	31	22	9	10	11	15
1921	13	11	12	15	34	31	27	27	26	13	14	13	20
1922	7	4	13	20	22	27	38	34	25	6	11	1	17
1923	7	7	7	17	13	23	23	16	15	17	8	0	13
1924	1	8	20	10	21	14	28	18	19	20	−6	0	13
1925	−13	−12	19	12	26	23	27	32	18	18	12	0	14
1926	−6	−19	14	21	23	26	30	22	17	9	3	−5	11
1927	−13	−8	6	7	26	30	31	33	33	25	−5	−2	14
1928	2	−19	−2	13	20	28	23	16	29	16	2	0	10
1929	7	12	27	29	24	35	27	39	21	10	12	5	21
1930	4	6	9	30	51	51	28	45	34	14	2	−3	22
Mean	1	0	12	17	26	29	29	30	23	15	6	2	15

* = Interpolated values.

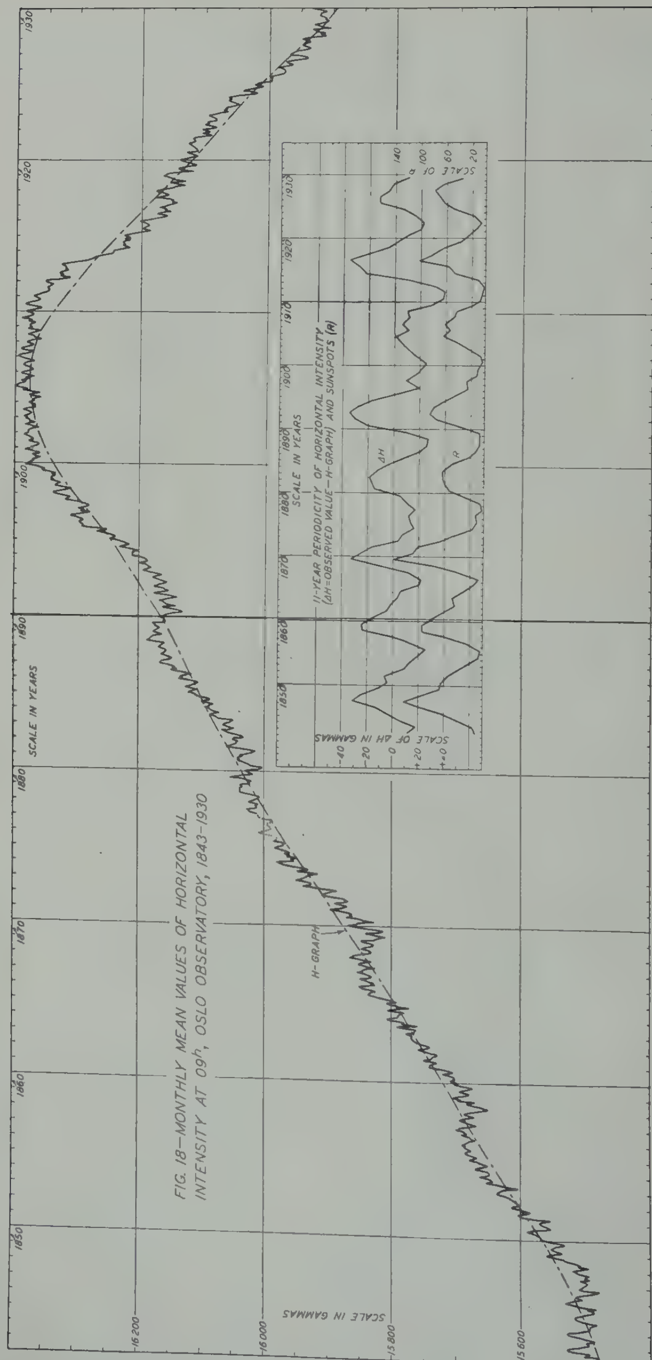


FIG. 18—MONTHLY MEAN VALUES OF HORIZONTAL INTENSITY AT 09h, OSLO OBSERVATORY, 1843-1930

any trace of an 8-year oscillation which is the dominating feature in the variation of the amplitude between H at 09^h and at 14^h. We may refer to Table E and a paper mentioned below.[15]

As mentioned above, I have made partial use of the supposed pronounced 11-year period as a hint to the distribution of the corrections for the base-line values during intervals where B_h could be fixed with the aid of absolute observations. It is, therefore, possible that I may have exaggerated the supposed parallelism with the sunspot-curve so much that a possible 8-year influence in the variation escaped notice. It may, however, be pointed out in this connection that the pronounced 11-year wave 1843 to 1853 is firmly based on absolute observations. From Table A we see that between 1844 and 1851 there is no break in the base-line value and that most of the other breaks from 1852 to 1856 are also established by absolute observations. However this may be, there can be no doubt that it is the 11-year period, and not the 8-year wave, which exerts the greatest influence on the variation of H at Oslo. In this connection I may quote Hansteen's statement made in 1858[16] that he has "found a periodic change of 11-1/9 years in the horizontal component of the magnetic intensity in which the epochs for maximum intensity agree with the epoch of minimum of the inclination and of the sunspots."

The data for H, on which he bases his theory are given in "Gauss units," and for the reduction Hansteen states that he used equation

TABLE 16

Year	No.	H	Year	No.	H
1820.71	11	1.5270	1841.55	26	1.5479
1822.68	6	1.5278	1842.49	22	1.5480
1823.54	6	1.5320	1843.26	22	1.5497
1825.98	2	1.5256	1845.39	2	1.5533
1827.49	10	1.5222	1846.08	3	1.5506
1828.16	5	1.5181	1850.31	2	1.5569
1830.53	6	1.5249	1851.62	2	1.5600
1831.75	4	1.5307	1854.48	2	1.5653
1832.43	5	1.5329	1855.56	23	1.5672
1834.98	6	1.5382	1856.67	2	1.5667
1838.58	7	1.5467	1857.45	4	1.5711
1839.56	46	1.5478	1858.38	9	1.5679
1840.32	17	1.5426			

TABLE 17

Year	From Table 16	From our reduction for 09^h	Diff.
	γ	γ	γ
1843	0.15497	0.15495	+ 2
1845	0.15533	0.15503	+20
1846	0.15506	0.15504	+ 2
1850	0.15569	0.15547	+22
1851	0.15600	0.15571	+29
1854	0.15653	0.15636	+17
1855	0.15672	0.15658	+14
1856	0.15667	0.15680	−13
1857	0.15711	0.15684	+27
1858	0.15679	0.15683	− 4

(29), it being understood that the observations were made with Dollond's cylinder which, as we may recall, was purchased as early as 1819. In this connection we may also recall the fact that the temperature-coefficient for Dollond's cylinder was found too high.

If we compare Hansteen's values in Table 16 with the corresponding yearly mean values for 09^h according to our reduction, we get the differences stated in the last column of Table 17, which shows that on

[15] K. F. Wasserfall, The long periodic variation in the diurnal range of magnetic horizontal component at Oslo Observatory, Terr. Mag., **43**, 45-46 (1938).

[16] Kristiania Forh. Vid. selsk. (1858).

an average Hansteen's figures are 12.6γ higher than ours for 09^h. We may remark that the average differences between the yearly mean values for 09^h and those calculated with 24-hour means amount to about 15γ for Rude Skov; hence we may conclude that the 24-hour mean for Oslo cannot be very far from those for 09^h if we add 15γ to these figures.

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FINAL RELATIVE SUNSPOT-NUMBERS FOR 1940

By W. Brunner

Table 1 contains the final sunspot-numbers for 1940, for the whole disk of the Sun, based on observations made at the Zürich Observatory, supplemented by series furnished by other cooperating observatories for

Table 1—*Final relative sunspot-numbers for the whole disk of the Sun for 1940*

Day	January	February	March	April	May	June	July	August	September	October	November	December
1	E39[c]	58[b]*	E 91[c]	E85[c]	E26[ac]	M 38[c]	91	69	E130[abc]	38	41*	27[a]*
2	37	59	74[b]	80[a]	28	41	67	60	112	33*	41	17*
3	42	58	M 96[c]	E65[ca]	23	E 77[cd]	77	67[d]	127	29	E 67[ac]*	E 29[c]*
4	69*	52	116[d]	46	25	80	47	E105[ac]	97[aa]	32	61[a]	E 45[c]
5	66[b]*	55[aa]*	E 92[c]	62[a]	19[a]*	58[a]	E 56[c]	103	W 91[ac]	35[a]	67	66[d]*
6	61*	E47[c]	81*	58[ad]	21	95[dd]	M 44[c]	111[d]	89[a]	M44[cdd]	43	68*
7	49*	E63[c]*	77	64	22	94	56[a]	E121[c]	E 68[c]	57*	56[d]	89[a]
8	38	64	E 72[c]	56	E32[c]	106	M 68[cc]	119[a]	62	60*	E 67[ac]	E 82[acd]
9	M47[c]*	E82[c]	46	W41[c]	E31[c]	103	E 97[ac]	129[b]	42	53	76	M108[aacc]
10	41	65*	47[aa]*	E59[c]	34	107	M122[cd]	148	49*	57[d]	63*	E142[c]
11	E50[c]	41[aad]	48[a]	50[a]	36	109	125[a]	E128[bcd]	40*	70*	60	157[a]
12	29	M69[c]*	E 76[c]	53	M53[acd]	M 94[aac]	126	124[b]	38[a]	77[abd]	66[a]	135*
13	34	62	74	53	62[a]	104	101	162[d]	E 37[c]	72[b]	M 99[c]	W158[ac]
14	61	E89[c]	76[d]	60[d]	93[a]	M 76[c]	76	128	41	66	E 70[ac]	149[ad]
15	E47[c]*	78*	49	74	91	82	62	110	M 32[c]	70[d]	92*	100[a]*
16	61[a]	73	M 70[c]	65[ad]	85	59[d]	74[a]	E 98[bc]	50[a]	71[a]*	100[a]	79*
17	52*	51[aa]	43[a]	65	77*	55*	W 60[c]	109[a]	E 56[cd]	59	88[d]	67
18	64	50	M 56[cd]	59	63[a]	51	62	114	79	71[d]*	87	60
19	59	M52[cd]*	78[a]	W71[cd]	69[a]	46[d]	66	E 97[ac]	100[bd]	61	65	29
20	M88[ac]	M65[ac]*	79[d]	79[a]	M61[c]	38	67	E126[bcd]	98	67	47	E 37[c]
21	71[a]	60[a]	85[d]	94[a]	E71[ac]	E 58[c]	52	124*	106[d]	64[b]	34	37*
22	50*	59[d]	E 92[c]	83	86	61[b]	M 58[c]	126	93	E74[c]	16	38*
23	52	44	E111[cd]	63[a]	85[d]	83	34[a]	116[a]	66	68	E 25[ac]*	27
24	34	40	115	W64[c]	67	E113[c]	34	94	61*	41[a]*	M 41[c]*	M 58[ac]
25	30[d]*	44	101[a]	56[ad]	E76[ac]	108[b]	E 48[c]	84	53*	M45[c]*	56[d]	51*
26	49*	E51[c]*	E108[bc]	50	57	E136[c]	37	E 71[c]	35*	53*	53	47*
27	50*	52	136[ad]	62	61[a]	117	E 50[c]*	75[d]	26[a]	52[a]*	M 52[c]	38[a]*
28	43*	46[a]	125	38	62	120[a]	59[d]	76	37	52*	46*	34[d]
29	45[d]*	M95[c]	98[a]	32	62[a]*	104[a]	53[a]	89[dd]	38	E46[c]*	42	55
30	50[d]*		86	35	53*	103	58	89	41*	49*	31	49
31	56*		85[a]		54		M 66[aac]	99[b]		38		38*
Mean	50.5	59.4	83.3	60.7	54.4	83.9	67.5	105.5	66.5	55.0	58.4	68.3

* =Observed at other observatories than Zürich.
a =Passage of an average-sized group through the central meridian.
b =Passage of a large group or spot through the central meridian.
c =New formation of a group developing into a middle-sized or large center of activity: *E*, on the eastern part of the Sun's disk; *W*, on the western part; *M*, in the central-circle zone.
d =Entrance of a large or average-sized center of activity on the east limb.

days (indicated by asterisks) on which no observations were possible at Zürich.

Table 2 gives the yearly means of the relative numbers, *R*, since the last minimum 1933 and the number of days without spots.

Table 2—*Yearly means of relative sunspot-numbers, R*

Year	*R*	Increase	No. spotless days
1933	5.7		240
1934	8.7	3.0	154
1935	36.1	27.4	20
1936	79.7	43.6	0
1937	114.4	34.7	0
1938	109.6	− 4.8	0
1939	88.8	−20.8	0
1940	67.8	−21.0	0

Figure 1 gives a graphical representation of the daily relative sunspot-numbers of 1940, the times being plotted as abscissas and the relative numbers as ordinates. The limits of the successive solar rotations are indicated by vertical arrows in the upper edge of the Figure. The secondary maxima and minima succeeding the rotation-periods do not represent real fluctuations in sunspot-activity, but are rather to be attributed to the influence of solar rotation, to a certain stability of the centers of activity for spots, and to the special distribution of these centers of activity in the direction of rotation.

Figure 2 shows the observed and smoothed monthly relative numbers

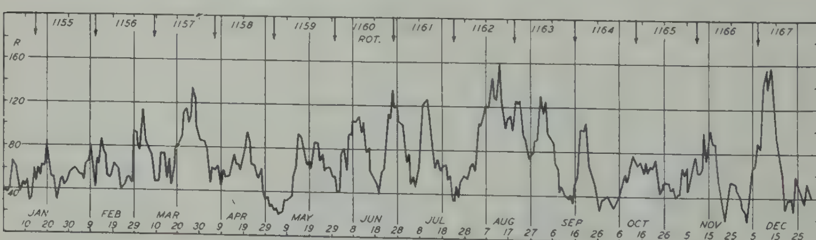

FIG. 1—DAILY RELATIVE SUNSPOT-NUMBERS FOR 1940

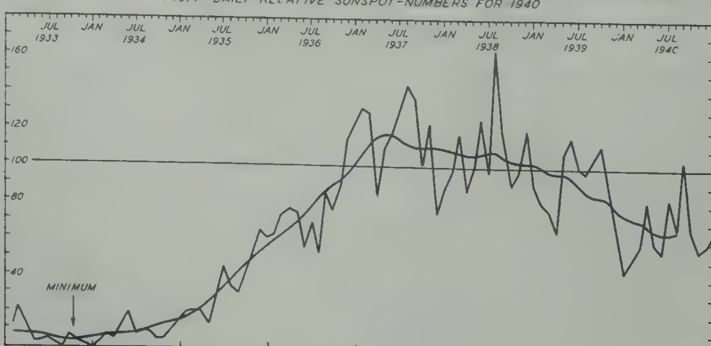

FIG. 2—OBSERVED AND SMOOTHED MONTHLY RELATIVE NUMBERS FOR 1933 TO 1940

for 1933 to 1940. The purpose of smoothing is to eliminate the secondary variations. The method of smoothing is as follows: For obtaining the mean of the epoch July 1, the average of the monthly means of the twelve months January to December is taken (m_1), and for the epoch August 1, the average of the monthly means for February to January (m_2). The mean of these $m=(m_1+m_2)/2$, which represents the smoothed relative number for the middle of July, is used for the construction of the curve.

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LETTERS TO EDITOR

(See also page 245)

PROVISIONAL SUNSPOT-NUMBERS FOR FEBRUARY TO APRIL, 1941

(Dependent alone on observation at Zürich Observatory)

Day	February	March	April
1	75*[a]	46	35
2	69	49[a]	26
3	65[a]	*E*50[c]	21
4	...	*E*48[c]	23
5	*M*85[cd]	41	...[d]
6	64[a]	45	...[d]
7	57	*M*47[ac]	39*[d]
8	43	31	41
9	58[d]	42[d]	51
10	47	40	51
11	36	*M*46[c]	59
12	30	60[a]	46
13	...	37	41[a]
14	29	37	30
15	27[a]	37	17
16	8(?)	*E*48[cd]	16
17	21	61	*W*31[c]
18	22	65	29[d]
19	*W*28[c]	70[b]	25
20	...	64	18
21	40[d]	76	20
22	26	57*[a]	20
23	15(?)	50*[d]	*M*36[c]
24	*E*46[cd]	39	27*[a]
25	54	47	...
26	46	40*	50*[d]
27	50[b]	43	35
28	56*[ad]	40[a]	43
29		34	43
30		17	*W*41[c]
31		...	
Means	43.9	46.9	33.9
No. days....	25	30	27

Mean for quarter, January to March, 1941: 45.1 (79 days)

*Observed at Locarno.
[a]Passage of an average-sized group through the central meridian.
[b]Passage of a large group or spot through the central meridian.
[c]New formation of a group developing into a middle-sized or large center of activity: *E*, on the eastern part of the Sun's disk; *W*, on the western part; *M*, in the central-circle zone.
[d]Entrance of a large or average-sized center of activity on the east limb.

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THE IONOSPHERE AT WATHEROO, WESTERN AUSTRALIA, OCTOBER, 1940, TO MARCH, 1941

By W. C. Parkinson

This report is a continuation of those already published in this Journal[1] and gives monthly mean hourly values of the heights and penetration-frequencies of the ionosphere as obtained by means of automatic multifrequency ionospheric recording apparatus located near Watheroo, Western Australia, in latitude 30° 19′.1 south, longitude 115° 52′.6 east of Greenwich, which operates over the frequency-range 0.516 to 16.0 Mc/sec.

Table 1 gives the monthly mean hourly values of the height of maximum electron-density (h^{max}), uncorrected for retardation in lower regions[2], and the minimum virtual height (h^{min}) for both the F_1- and F_2-regions, the penetration-frequencies for the E-, F_1-, and F_2-regions, and the lowest frequency at which echoes were observed when that frequency was higher than 0.516 Mc/sec.

Table 1—*Mean hourly values of ionospheric data, Watheroo Magnetic Observatory, October, 1940, to March, 1941*

120° east mean time	$h^{max}_{F_1}$	$h^{min}_{F_1}$	$h^{max}_{F_2}$	$h^{min}_{F_2}$	f^0_E	$f^0_{F_1}$	$f^0_{F_2}$	f_{min}
h	*km*	*km*	*km*	*km*	*Mc/sec*	*Mc/sec*	*Mc/sec*	*Mc/sec*
				October, 1940				
00			360	264			5.42	
01			348	258			5.15	
02			347	258			4.67	
03			362	269			4.22	
04			368	277			3.98	
05			359	283	0.85		4.08	
06	258	252	298	251	1.94	3.20	5.60	0.56
07	244	235	300	261	2.61	4.11	6.91	0.68
08	240	227	311	284	3.04	4.67	7.69	0.79
09	238	223	327	303	3.33	4.92	8.24	0.82
10	227	209	346	313	3.49	5.03	8.69	0.87
11	228	212	357	325	3.61	5.19	9.17	0.89
12	232	214	354	319	3.61	5.18	9.57	0.90
13	230	216	349	316	3.60	5.12	9.66	0.92
14	238	220	346	309	3.48	5.07	9.56	0.89
15	237	223	340	296	3.29	4.87	9.31	0.83
16	247	229	333	283	2.95	4.48	8.94	0.77
17	248	241	323	256	2.45	3.85	8.70	0.68
18			314	240	1.65		8.33	0.60
19			332	237			7.63	
20			348	244			6.89	
21			362	259			6.31	
22			373	274			6.00	
23			369	272			5.83	

[1]Terr. Mag., **44**, 199-204 and 341-343 (1939); **45**, 45-47, 169-172, and 471-476 (1940); **46**, 79-82 (1941).
[2]Phys. Rev., **57**, 87-94 (1940).

TABLE 1—*Mean hourly values of ionospheric data, Watheroo Magnetic Observatory, October, 1940, to March, 1941—Continued*

120° east mean time	$h^{max}_{F_1}$	$h^{min}_{F_1}$	$h^{max}_{F_2}$	$h^{min}_{F_2}$	f^o_E	$f^o_{F_1}$	$f^o_{F_2}$	f_{min}
h	*km*	*km*	*km*	*km*	*Mc/sec*	*Mc/sec*	*Mc/sec*	*Mc/sec*
				November, 1940				
00			362	279			6.44	
01			353	262			6.10	
02			356	261			5.41	
03			359	264			5.01	
04			358	269			4.58	
05			344	279	1.44		4.60	0.52
06	269	259	318	281	2.20	3.58	5.44	0.65
07	251	239	337	322	2.73	4.30	6.09	0.74
08	241	228	346	349	3.14	4.71	6.84	0.81
09	239	226	360	353	3.40	4.95	7.63	0.85
10	226	216	366	346	3.54	5.03	8.32	0.92
11	233	214	368	341	3.64	5.24	8.96	0.90
12	227	218	367	340	3.62	5.19	9.23	0.93
13	241	222	363	334	3.57	5.20	9.57	0.93
14	244	226	364	332	3.45	5.14	9.55	0.91
15	250	235	357	322	3.30	4.96	9.44	0.87
16	251	240	347	307	3.08	4.61	9.29	0.83
17	245	236	335	275	2.61	4.05	9.14	0.78
18	255	250	330	259	1.94	3.20	8.91	0.66
19			327	241	1.24		8.63	0.52
20			349	243			7.64	
21			361	261			7.03	
22			378	275			6.55	
23			384	282			6.42	
				December, 1940				
00			349	275			6.20	
01			343	261			5.70	
02			350	265			5.09	
03			359	272			4.76	
04			355	266			4.46	
05	290	265	318	273	1.43	(3.00)	4.47	
06	261	248	309	269	2.19	3.60	5.12	0.58
07	240	231	342	314	2.69	4.17	5.73	0.66
08	230	221	363	360	3.12	4.53	6.22	0.78
09	229	223	367	357	3.42	4.74	6.77	0.82
10	216	213	361	354	3.55	4.87	7.37	0.87
11	232	223	374	365	3.67	4.99	7.60	0.90
12	235	225	385	381	3.59	4.93	7.73	0.90
13	232	225	372	367	3.64	4.97	7.98	0.93
14	231	229	376	367	3.58	4.94	7.94	0.91
15	233	230	366	353	3.45	4.78	7.96	0.88
16	247	232	359	337	3.21	4.66	8.01	0.85
17	249	236	342	312	2.85	4.25	8.04	0.74
18	260	245	323	279	2.22	3.62	8.07	0.66
19			328	254	1.45		7.82	
20			355	249			7.33	
21			362	265			6.64	
22			376	280			6.31	
23			367	287			6.28	

TABLE 1—*Mean hourly values of ionospheric data, Watheroo Magnetic Observatory, October, 1940, to March, 1941—Continued*

120° east mean time	$h^{max}_{F_1}$	$h^{min}_{F_1}$	$h^{max}_{F_2}$	$h^{min}_{F_2}$	f^o_E	$f^o_{F_1}$	$f^o_{F_2}$	f_{min}
h	km	km	km	km	Mc/sec	Mc/sec	Mc/sec	Mc/sec
				January, 1941				
00			343	267			5.59	
01			337	255			5.01	
02			348	261			4.31	
03			350	272			3.91	
04			350	271			3.69	
05			331	277	1.14		3.57	
06	268	257	312	269	1.98	3.23	4.56	0.56
07	244	238	309	288	2.56	3.91	5.28	0.65
08	236	225	332	329	3.01	4.48	5.89	0.76
09	228	219	365	352	3.25	4.64	6.56	0.79
10	220	216	371	362	3.46	4.80	7.24	0.83
11	220	218	369	354	3.48	4.87	7.84	0.86
12	219	210	367	352	3.59	4.92	8.12	0.86
13	227	218	353	336	3.58	4.91	8.31	0.89
14	228	228	347	331	3.55	4.84	8.15	0.86
15	224	217	340	326	3.39	4.72	7.88	0.82
16	227	223	326	315	3.22	4.52	7.51	0.79
17	240	228	319	305	2.90	4.29	7.08	0.68
18	246	239	313	271	2.28	3.63	6.84	0.57
19			325	256	(1.00)		6.68	
20			342	260			6.55	
21			362	275			6.16	
22			366	283			6.02	
23			358	272			5.84	
				February, 1941				
00			358	277			5.04	
01			342	271			4.83	
02			337	264			4.50	
03			333	261			4.04	
04			342	269			3.60	
05			347	272			3.39	
06	275	250	311	264	1.68	3.05	3.98	0.53
07	251	236	305	259	2.32	3.84	4.93	0.64
08	236	229	318	296	2.81	4.24	5.42	0.74
09	220	215	330	339	3.06	4.46	5.96	0.79
10	218	214	344	334	3.32	4.61	6.42	0.86
11	213	213	352	345	3.39	4.71	6.73	0.89
12	215	211	352	341	3.51	4.79	7.14	0.89
13	219	216	350	339	3.50	4.80	7.35	0.91
14	224	219	340	329	3.41	4.74	7.37	0.89
15	233	227	330	318	3.29	4.61	7.26	0.86
16	235	228	323	308	3.08	4.45	7.01	0.78
17	242	231	312	286	2.77	4.10	6.76	0.70
18	251	242	302	251	2.17	3.40	6.60	0.57
19			308	239			6.40	
20			335	241			6.06	
21			358	268			5.41	
22			366	276			5.15	
23			366	285			5.05	

TABLE 1—*Mean hourly values of ionospheric data, Watheroo Magnetic Observatory, October, 1940, to March, 1941—Continued*

120° east mean time	$h^{max}_{F_1}$	$h^{min}_{F_1}$	$h^{max}_{F_2}$	$h^{min}_{F_2}$	f^o_E	$f^o_{F_1}$	$f^o_{F_2}$	f_{min}
h	km	km	km	km	Mc/sec	Mc/sec	Mc/sec	Mc/sec
				March, 1941				
00			342	266			4.38	
01			346	265			4.24	
02			342	263			4.15	
03			329	252			3.95	
04			324	256			3.57	
05			329	261			3.33	
06			296	257	1.33		3.79	0.50
07	240	239	271	247	2.08	3.28	5.21	0.65
08	241	232	284	260	2.62	3.93	6.06	0.72
09	226	212	292	283	3.01	4.41	6.68	0.75
10	219	211	301	290	3.21	4.60	7.32	0.80
11	216	193	318	301	3.29	4.71	7.83	0.85
12	212	202	311	296	3.31	4.79	8.49	0.91
13	226	206	319	296	3.25	4.73	8.76	0.89
14	232	223	310	288	3.27	4.73	8.85	0.88
15	235	225	310	286	3.19	4.52	8.58	0.81
16	240	231	304	277	2.98	4.26	8.33	0.77
17	243	236	296	250	2.46	3.68	8.05	0.70
18			285	241	1.75		7.59	0.56
19			305	225			6.53	
20			332	233			5.62	
21			350	254			5.07	
22			352	265			4.76	
23			344	262			4.52	

Figures 1 and 2 give the data in graphical form; the values of h^{min} lie along the continuous line while those of h^{max} are indicated by the broken line.

The 120° east meridian standard times of sunrise and sunset at the Earth's surface for the middle of each month are shown by the broken vertical lines.

Table 2 gives root-mean-square values of F_2-region penetration-frequencies. Since ionization is proportional to the square of frequency, these data are more representative of *average ionization* than the normally used means of penetration-frequencies. The difference between the root-mean-square values of Table 2 and the arithmetical-mean values of Table 1 is an approximate measure of the scatter in individual observations during the month for that particular hour. Root-mean-square values for the E-region, F_1-region, and minimum frequency received have been discontinued because of the absence of appreciable differences between the root-mean-square and arithmetical-mean values.

The magnetic storm of March 1 and 2, 1941, was accompanied by abnormal ionospheric conditions. Figure 3 shows the variation of ion-

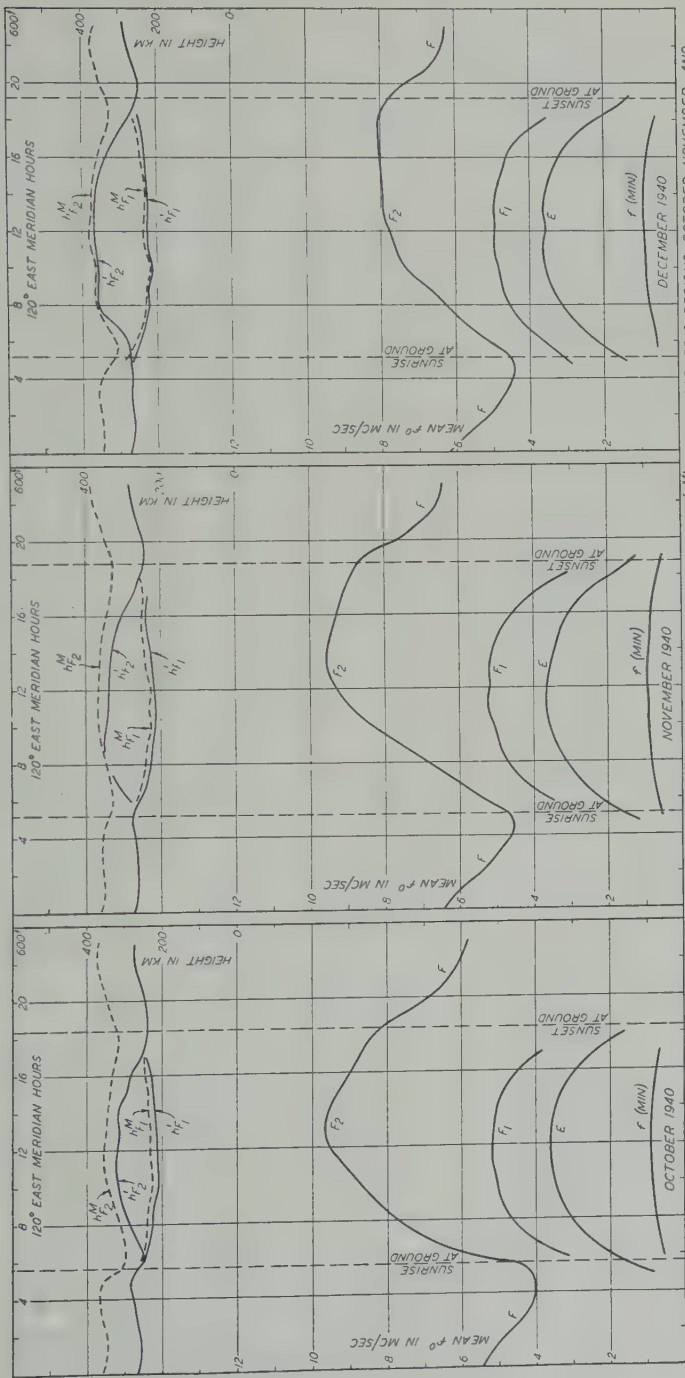


FIG. 1—MEAN CRITICAL FREQUENCY (f^0), MINIMUM VIRTUAL HEIGHT (h'), AND HEIGHT OF MAXIMUM ION-DENSITY (h^M), FOR IONOSPHERIC REGIONS, OCTOBER, NOVEMBER, AND DECEMBER, 1940, WATHEROO, WESTERN AUSTRALIA

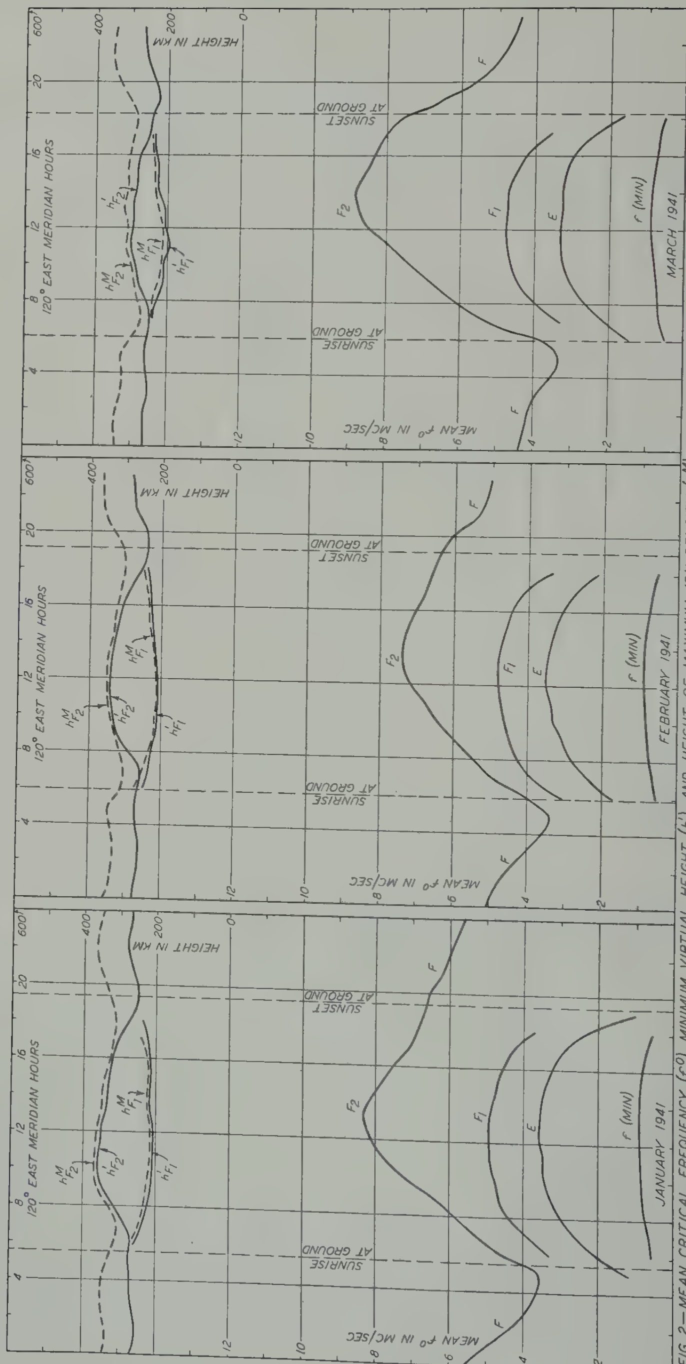
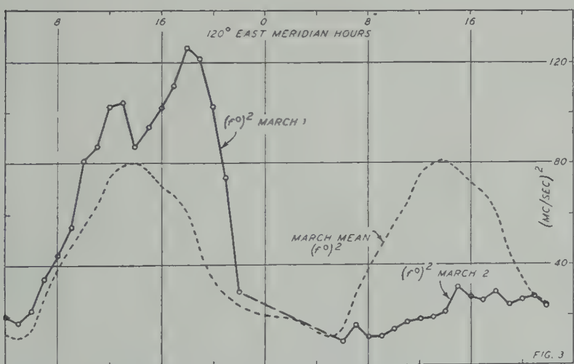


FIG. 2—MEAN CRITICAL FREQUENCY (f^0), MINIMUM VIRTUAL HEIGHT (h'), AND HEIGHT OF MAXIMUM ION-DENSITY (h^M), FOR IONOSPHERIC REGIONS, JANUARY, FEBRUARY, AND MARCH, 1941, WATHEROO, WESTERN AUSTRALIA

TABLE 2—*Root-mean-square values of F_2-region penetration-frequencies ($f^o{}_{F_2}$), Watheroo Magnetic Observatory, October to December, 1940*

120° east mean time	Oct.	Nov.	Dec.	120° east mean time	Oct.	Nov.	Dec.
h	*Mc/sec*	*Mc/sec*	*Mc/sec*	*h*	*Mc/sec*	*Mc/sec*	*Mc/sec*
00	5.50	6.47	6.25	12	9.62	9.32	7.87
01	5.20	6.13	5.74	13	9.73	9.65	8.09
02	4.72	5.45	5.13	14	9.62	9.64	8.06
03	4.28	5.07	4.80	15	9.37	9.55	8.08
04	4.03	4.64	4.50	16	9.00	9.40	8.14
05	4.13	4.65	4.52	17	8.77	9.23	8.16
06	5.63	5.48	5.18	18	8.39	9.02	8.16
07	6.95	6.15	5.78	19	7.68	8.71	7.89
08	7.74	6.92	6.27	20	6.95	7.70	7.39
09	8.31	7.77	6.84	21	6.36	7.08	6.67
10	8.75	8.43	7.44	22	6.05	6.61	6.34
11	9.22	9.06	7.71	23	5.89	6.48	6.33

density from 04^h to 22^h, March 2, compared to the mean of the month. Scattering became so bad that critical frequencies could not be measured between 23^h, March 1, and 05^h, March 2. The disturbance of March 28-31 gave rise to considerable scattering during the night March 29-30 and absence of F_2-layer during most of March 31.



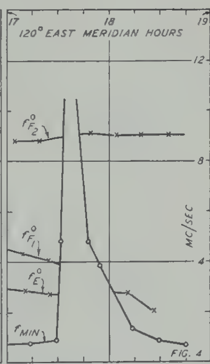


FIG. 3—COMPARISON OF RELATIVE ION-DENSITY DURING MAGNETIC DISTURBANCE OF MARCH 1 AND 2, 1941 WITH CURVE OF MEAN FOR MARCH 1941, WATHEROO MAGNETIC OBSERVATORY

FIG. 4—EFFECT OF RADIO FADE-OUT OF FEBRUARY 28, 1941, WATHEROO MAGNETIC OBSERVATORY

Four fade-outs were recorded during the first quarter of 1941—one on January 30, two on February 28, and one on March 3. The second, that on February 28, was the only complete fade-out, the F_2-layer being obscured for about ten minutes only. Figure 4 shows the progression of this fade-out. The other three obscured the E-layer only.

WATHEROO MAGNETIC OBSERVATORY,
Watheroo, Western Australia, April 19, 1941

REVIEWS AND ABSTRACTS

G. Simpson and G. D. Robinson. *The distribution of electricity in thunder-clouds, II.* Proc. R. Soc., A, **177**, 281-329 (1941).

The exploration of thunder-clouds by the more direct method first used by Simpson and Scrase[1] was extended at the Kew Observatory during the years 1937 to 1939. In all 62 sounding were made, 38 of which yielded legible records. In the case of six soundings the fields were too small to be registered, 14 records were defective, and four were not recovered. The individual records for 35 soundings, representing eight storms, are exhibited in the present report. As many as six successful soundings were obtained at intervals during each of two storms thus giving a cross-section which facilitates the interpretation. These additional data and an improved method of interpretation corroborate the main conclusions of the previous report, namely, that "each thunder-cloud has positive electricity in the upper half of the cloud, negative electricity in the lower half, and in most storms, if not in all, there is a concentrated positive charge below the main negative charge."

The upper positive and the negative charges are generally found at temperatures below the freezing point of water whereas the temperature where the lower positive charge is apparently located is reported to be above the freezing point in most cases. The main part of this distribution was clearly indicated by measurements made by various observers, during recent decades, of the electric field at the ground in the vicinity of thunder-storms but the more direct indications obtained from the soundings made at Kew are a valuable supplement to the other indications. The argument, presented in this report, for the existence of a positive charge in the lower part of the cloud or just below it, is more convincing than that given in the first report.

The records are interpreted with the aid of a model charge-distribution which consists of three colinear charges as follows: (*a*) A positive charge of 24 coulombs uniformly distributed in a sphere of two-km radius with its center at an altitude of six km; (*b*) below this a negative charge of 20 coulombs in a sphere of one-km radius centered at an altitude of three km; and (*c*) a positive charge of four coulombs in a sphere of 0.5-km radius at 1.5-km altitude.

Most of the records from soundings and the records of field (predischarge) at the ground are explainable in terms of this model provided the drift of the balloon toward the active center of the storm varies from time to time, or from storm to storm, in a suitable manner. The potential-gradient at the ground for this distribution should first show some increase over the normal value followed by a reversal to negative values but, with closer approach of the storm-center, there should follow an increase, and a maximum should be reached when the center is overhead. Then as the storm passes on the variation should be symmetrical with that which preceded. S. K. Banerji[2] found that type of variation of the field about thunder-storms in India and Schonland[3] concluded that a variation of that type is found chiefly about thunder-clouds from which heavy rain is falling. This simple model therefore seems to provide a fairly satisfactory qualitative interpretation of the observations of field-intensity about a thunder-storm. These investigations certainly have blazed a new trail for the exploration of thunder-storms.

O. H. Gish

[1]Proc. R. Soc., A, **161**, 309-352 (1937).
[2]Phil. Trans. R. Soc., A, **231**, 1-27 (1932).
[3]Proc. R. Soc., A, **118**, 233-251 (1928).

THE IONOSPHERE AT HUANCAYO, PERU, OCTOBER, 1940, TO MARCH, 1941

By H. W. Wells, P. G. Ledig, R. C. Coile, and M. W. Jones

This report is a continuation of those already published in this Journal[1] and gives monthly mean hourly values of the heights and penetration-frequencies of the ionospheric regions as obtained from the automatic multifrequency ionospheric recording apparatus located near Huancayo, Peru, South America, in latitude 12° 02′.7 south, longitude 75° 20′.4 west of Greenwich, which operates over a frequency-range 0.516 to 16.0 Mc/sec. A complete discussion of these data will be made in an annual summary.

Table 1 gives the monthly mean hourly values of the actual heights of maximum electron-density (h^{max}), uncorrected for retardation in

Table 1—*Mean hourly values of ionospheric data, Huancayo Magnetic Observatory, October, 1940, to March, 1941*

75° west mean time	$h^{max}_{F_1}$	$h^{min}_{F_1}$	$h^{max}_{F_2}$	$h^{min}_{F_2}$	f^o_E	$f^o_{F_1}$	$f^o_{F_2}$	f_{min}
h	*km*	*km*	*km*	*km*	*Mc/sec*	*Mc/sec*	*Mc/sec*	*Mc/sec*
				October, 1940				
00			335	251			10.33	
01			327	244			8.57	
02			327	251			7.16	
03			324	259			6.35	
04			317	264			5.51	
05			322	274	0.96		5.06	0.70
06			319	264	2.11		7.64	0.79
07			343	257	2.75		10.32	1.01
08	255	243	386	290	3.34	4.90	11.78	1.24
09	238	234	459	302	3.83	5.13	12.40	1.76
10	239	232	502	307	4.07	5.23	12.03	1.92
11	231	230	483	317	4.17	5.22	11.18	1.94
12	229	226	483	317	4.17	5.19	10.94	1.96
13	224	224	490	312	4.05	5.04	11.05	1.93
14	229	225	487	312	3.87	4.99	11.34	1.84
15	244	228	496	304	3.54	4.83	11.57	1.56
16	265	238	495	299	2.98	4.57	11.69	1.22
17			493	275	2.32		11.69	0.99
18			483	298	1.22		11.61	0.71
19			534	360	0.76		11.03	0.64
20			507	344			10.56	
21			447	298			10.50	
22			392	287			10.69	
23			362	273			10.60	

[1]Terr. Mag., **43**, 169-171, 257-260, and 467-470 (1938); **44**, 85-88, 195-198, 321-325, and 395-399 (1939); **45**, 49-52, 155-158, and 477-483 (1940); **46**, 83-86 (1941).

TABLE 1—*Mean hourly values of ionospheric data, Huancayo Magnetic Observatory, October, 1940, to March, 1941—Continued*

75° west mean time	$h^{max}_{F_1}$	$h^{min}_{F_1}$	$h^{max}_{F_2}$	$h^{min}_{F_2}$	f^o_E	$f^o_{F_1}$	$f^o_{F_2}$	f_{min}
h	*km*	*km*	*km*	*km*	*Mc/sec*	*Mc/sec*	*Mc/sec*	*Mc/sec*
				November, 1940				
00			358	286			7.13	
01			347	272			6.40	
02			334	274			5.89	
03			321	259			5.48	
04			304	261			4.73	
05			336	269	1.00		4.57	0.70
06	265	252	315	259	2.20	2.23	7.81	0.82
07	255	238	337	257	2.79	4.33	10.02	1.04
08	251	236	384	290	3.35	4.90	11.20	1.22
09	241	233	434	306	3.85	5.05	11.73	1.50
10	232	228	482	313	4.09	5.21	11.87	1.75
11	231	225	501	318	4.08	5.24	11.76	1.88
12	229	225	491	324	4.20	5.25	11.58	1.93
13	230	223	502	321	4.12	5.13	11.64	1.93
14	234	224	503	316	3.99	5.01	11.73	1.85
15	246	232	496	316	3.64	4.86	11.59	1.57
16	268	240	505	291	2.98	4.71	11.53	1.19
17			480	267	2.34		11.42	0.96
18			467	289	1.39		11.24	0.80
19			495	326	0.82		10.63	0.65
20			502	331			9.58	
21			493	345			8.98	
22			453	348			8.24	
23			407	319			7.63	
				December, 1940				
00			398	372			6.26	
01			380	376			5.49	
02			395	378			4.99	
03			387	354			4.55	
04			352	316			4.33	
05			346	288	0.96		4.03	0.69
06			332	265	2.14		6.74	0.72
07	262	240	350	276	2.60	4.63	9.00	0.94
08	253	234	389	302	3.19	4.94	10.24	1.09
09	249	231	440	329	3.76	5.17	10.73	1.30
10	242	228	484	350	4.04	5.31	10.84	1.58
11	237	223	508	368	4.16	5.39	10.68	1.85
12	235	224	509	382	4.22	5.42	10.45	1.98
13	243	221	492	379	4.13	5.39	10.51	1.90
14	256	224	493	374	4.03	5.35	10.90	1.72
15	262	231	480	353	3.74	5.17	11.45	1.41
16	281	232	474	340	3.08	5.05	11.40	1.17
17	302	257	480	273	2.36	4.80	11.20	0.91
18			477	282	1.70		11.00	0.78
19			469	306	0.95		10.57	0.65
20			500	332			9.69	
21			501	365			8.68	
22			467	369			7.97	
23			431	367			7.20	

TABLE 1—*Mean hourly values of ionospheric data, Huancayo Magnetic Observatory, October, 1940, to March, 1941—Continued*

75° west mean time	$h^{max}_{F_1}$	$h^{min}_{F_1}$	$h^{max}_{F_2}$	$h^{min}_{F_2}$	f^o_E	$f^o_{F_1}$	$f^o_{F_2}$	f_{min}
h	km	km	km	km	Mc/sec	Mc/sec	Mc/sec	Mc/sec
				January, 1941				
00			340	298			6.73	
01			324	284			5.61	
02			324	280			4.89	
03			320	271			4.31	
04			303	261			3.88	
05			307	271	0.79		3.41	0.69
06			323	263	1.76		5.68	0.78
07	256	233	337	264	2.49	4.56	8.11	0.95
08	242	224	390	315	3.04	4.88	9.15	1.12
09	231	218	447	334	3.61	5.07	9.45	1.35
10	226	215	470	365	3.87	5.18	9.27	1.68
11	219	214	470	373	4.03	5.17	9.10	1.86
12	214	208	478	385	4.10	5.19	9.11	1.90
13	216	207	460	377	3.96	5.17	9.35	1.85
14	220	209	455	367	3.93	5.10	9.76	1.76
15	238	214	448	348	3.64	5.11	10.06	1.46
16	262	217	460	339	3.06	4.99	10.31	1.17
17	278	238	443	274	2.51	4.79	10.41	1.00
18			420	275	1.79		10.29	0.84
19			424	292	0.96		10.07	0.73
20			459	325			9.08	
21			436	335			8.34	
22			412	337			8.04	
23			373	321			7.55	
				February, 1941				
00			317	242			8.40	
01			311	248			7.34	
02			319	260			6.36	
03			313	265			5.75	
04			316	267			5.25	
05			297	256	0.78		4.68	0.65
06			314	261	1.64		5.61	0.71
07	250	235	314	245	2.42	4.34	8.20	0.90
08	235	223	347	285	2.97	4.82	9.52	1.08
09	227	223	396	308	3.61	5.01	10.22	1.31
10	221	218	439	327	3.92	5.09	10.40	1.45
11	213	217	450	337	4.03	5.08	10.16	1.71
12	211	213	454	347	4.13	5.07	9.97	1.79
13	208	213	449	350	4.08	5.04	10.03	1.78
14	215	208	444	334	3.96	5.00	10.37	1.66
15	222	215	449	323	3.73	4.95	10.59	1.33
16	242	217	454	312	3.04	4.80	10.73	1.20
17	267	237	446	252	2.60	4.56	10.58	0.98
18			431	269	1.69		10.49	0.80
19			447	307	0.82		10.20	0.67
20			452	338			9.35	
21			411	317			8.94	
22			383	290			8.69	
23			341	263			8.59	

TABLE 1—*Mean hourly values of ionospheric data, Huancayo Magnetic Observatory, October, 1940, to March, 1941—Continued*

75° west mean time	$h^{max}_{F_1}$	$h^{min}_{F_1}$	$h^{max}_{F_2}$	$h^{min}_{F_2}$	f^o_E	$f^o_{F_1}$	$f^o_{F_2}$	f_{min}
h	*km*	*km*	*km*	*km*	*Mc/sec*	*Mc/sec*	*Mc/sec*	*Mc/sec*
				March, 1941				
00			301	238			8.57	
01			308	239			7.40	
02			311	258			5.84	
03			311	265			4.93	
04			321	280			4.33	
05			346	296	0.86		3.78	0.70
06			317	273	1.53		5.14	0.82
07	262	247	309	260	2.40	4.46	8.23	0.95
08	252	235	360	292	2.88	4.72	9.87	1.10
09	239	231	430	306	3.54	4.86	10.37	1.35
10	232	227	457	332	3.82	4.96	10.19	1.61
11	226	222	458	346	3.99	4.97	9.87	1.77
12	228	223	467	352	4.06	4.98	9.44	1.82
13	223	218	459	340	4.01	4.94	9.19	1.81
14	224	218	446	337	3.87	4.93	9.51	1.68
15	236	219	442	320	3.42	4.78	9.96	1.38
16	259	222	448	304	2.83	4.70	10.29	1.22
17	275	250	446	265	2.42	4.60	10.43	1.02
18			444	279	1.47		10.26	0.88
19			468	337	0.87		9.66	0.72
20			439	342			9.31	
21			375	294			9.39	
22			339	257			9.23	
23			319	237			9.14	

lower regions[2], and the minimum virtual height (h^{min}) for both the F_1- and F_2-regions, the penetration-frequencies for the E-, F_1-, and F_2-regions, and the lowest frequency at which echoes were observed when that frequency was greater that 0.516 Mc/sec.

Figures 1 and 2 give the data in graphical form; the values of h^{min} lie along the continuous line while those of h^{max} are indicated by the broken line.

The 75° west meridian standard times of sunrise and sunset at the Earth's surface for the middle of each month are shown by the broken vertical lines.

Table 2 gives root-mean-square values of F_2-region penetration-frequencies. Since ionization is proportional to the square of frequency, these data are more representative of *average ionization* than the normally used means of penetration-frequencies. The difference between the root-mean-square values of Table 2 and the arithmetical-mean values of Table 1 is an approximate measure of the scatter in individual observa-

[2]Phys. Rev., 57, 87-94 (1940).

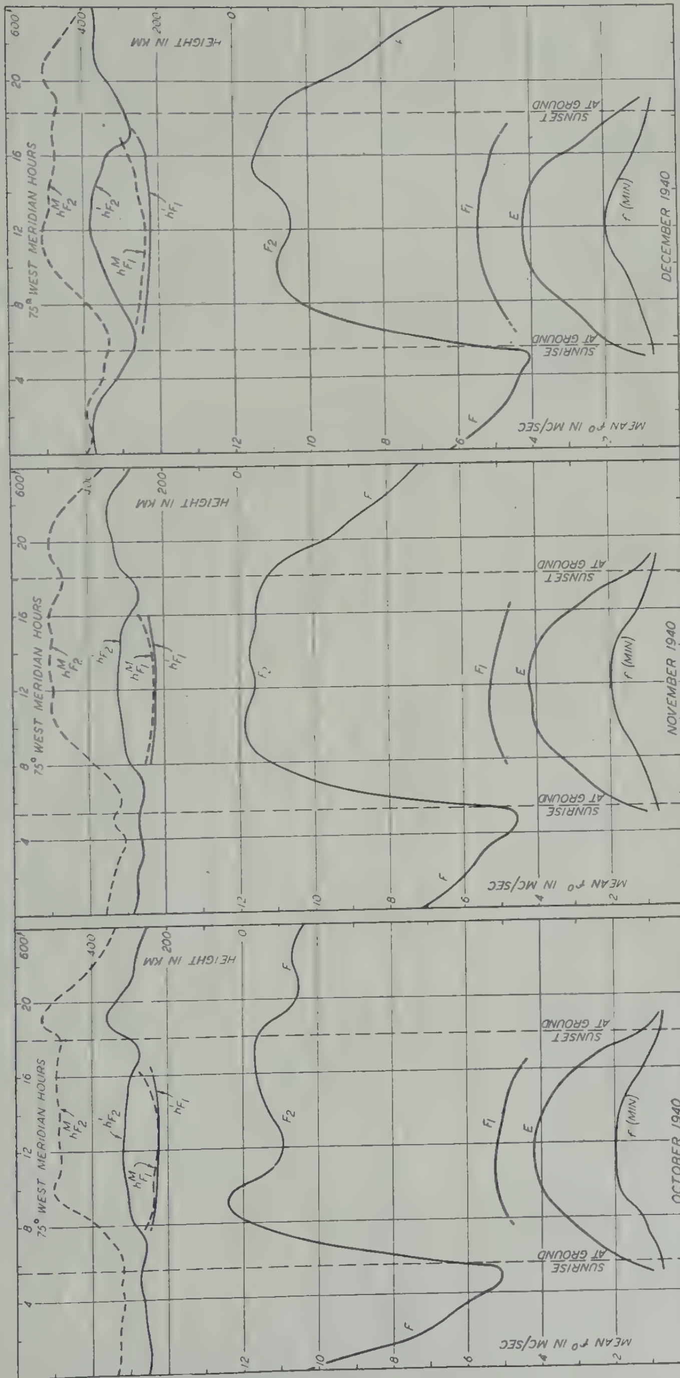


FIG. 1—MEAN CRITICAL FREQUENCY (f°), MINIMUM VIRTUAL HEIGHT (h'), AND HEIGHT OF MAXIMUM ION-DENSITY (h^M), FOR IONOSPHERIC REGIONS, OCTOBER, NOVEMBER, AND DECEMBER, 1940, HUANCAYO, PERU

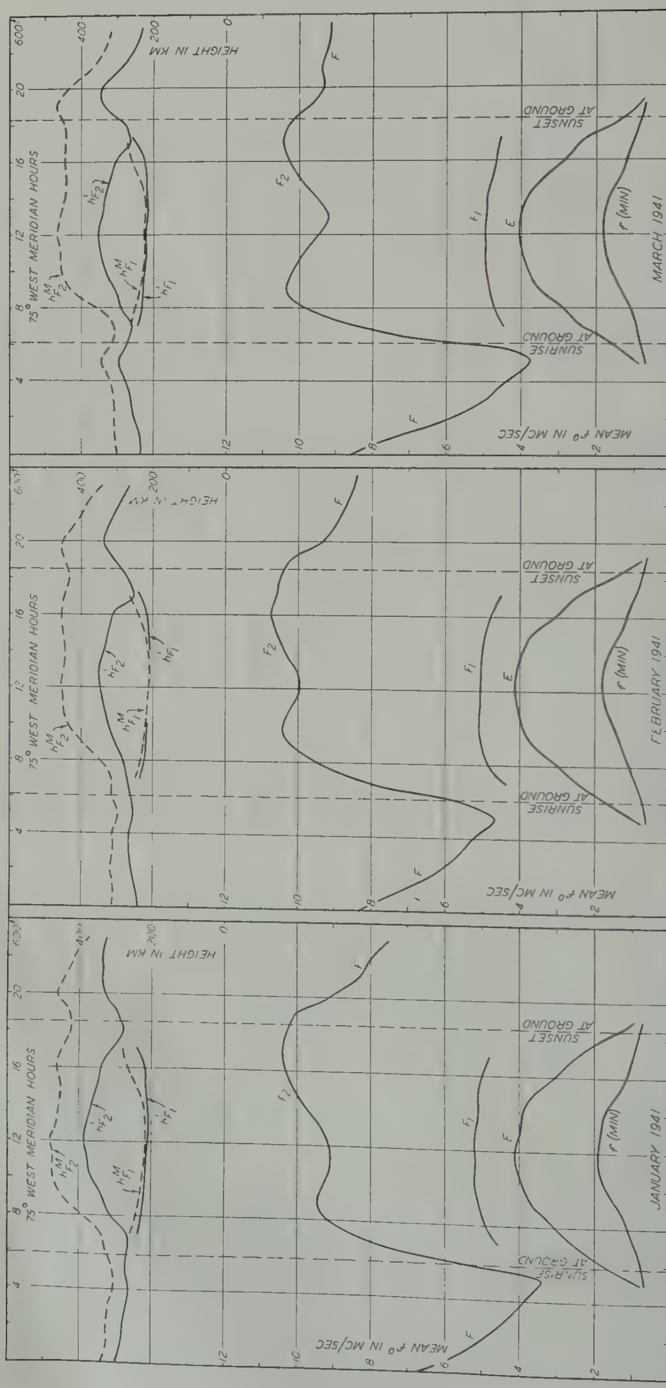


FIG. 2—MEAN CRITICAL FREQUENCY (f^0), MINIMUM VIRTUAL HEIGHT (h'), AND HEIGHT OF MAXIMUM ION-DENSITY (h^M), FOR IONOSPHERIC REGIONS, JANUARY, FEBRUARY, AND MARCH, 1941, HUANCAYO, PERU

tions during the month for that particular hour. Root-mean-square values for the E-region, F_1-region, and minimum frequency received have been discontinued because of the absence of appreciable differences between the root-mean-square and arithmetical-mean values.

TABLE 2—*Root-mean-square values of F_2-region penetration-frequencies ($f^o_{F_2}$), Huancayo Magnetic Observatory, October, 1940, to March, 1941*

75° west mean time	Oct.	Nov.	Dec.	75° west mean time	Oct.	Nov.	Dec.
h	*Mc/sec*	*Mc/sec*	*Mc/sec*	*h*	*Mc/sec*	*Mc/sec*	*Mc/sec*
00	10.49	7.27	6.39	12	11.05	11.65	10.53
01	8.68	6.53	5.46	13	11.13	11.71	10.56
02	7.34	6.08	5.07	14	11.43	11.78	10.94
03	6.55	5.68	4.64	15	11.63	11.66	11.47
04	5.74	4.99	4.42	16	11.73	11.61	11.46
05	5.24	4.64	4.14	17	11.73	11.56	11.21
06	7.68	7.87	6.77	18	11.65	11.34	11.03
07	10.33	10.05	9.03	19	11.10	10.70	10.68
08	11.78	11.20	10.26	20	10.65	9.65	9.72
09	12.43	11.76	10.76	21	10.59	9.07	8.70
10	12.09	11.92	10.88	22	10.78	8.38	8.03
11	11.24	11.81	10.74	23	10.69	7.86	7.32

75° west mean time	Jan.	Feb.	Mar.	75° west mean time	Jan.	Feb.	Mar.
h	*Mc/sec*	*Mc/sec*	*Mc/sec*	*h*	*Mc/sec*	*Mc/sec*	*Mc/sec*
00	6.87	8.52	8.74	12	9.20	10.09	9.52
01	5.70	7.46	7.65	13	9.43	10.16	9.25
02	4.96	6.48	6.11	14	9.84	10.51	9.55
03	4.42	5.90	5.22	15	10.11	10.68	10.00
04	4.36	5.42	4.69	16	10.35	10.78	10.34
05	3.52	4.94	4.12	17	10.45	10.64	10.49
06	5.70	5.68	5.24	18	10.36	10.57	10.32
07	8.14	8.24	8.26	19	10.12	10.23	9.73
08	9.21	9.57	9.89	20	9.15	9.40	9.43
09	9.54	10.28	10.42	21	8.44	9.03	9.53
10	9.35	10.49	10.27	22	8.15	8.80	9.37
11	9.18	10.28	9.99	23	7.67	8.70	9.30

HUANCAYO MAGNETIC OBSERVATORY,
Huancayo, Peru, April 19, 1941

NOTES

(See also page 254)

9. *Twenty-second annual meeting, American Geophysical Union*—The twenty-second annual meetings of the American Geophysical Union and of its eight sections were held in Washington, D. C., April 30, May 1, 2, and 3, 1941. In the course of these meetings some 128 papers and reports dealing with geophysical research were presented.

The program of the Section of Terrestrial Magnetism and Electricity included the following ten papers: (1) The reduction of magnetic observations to mean of year, by E. H. Vestine; (2) Improvements and modifications to la Cour magnetograph, by J. H. Nelson and A. K. Ludy; (3) A computation of the average depth to the bottom of the Earth's magnetic crust based on a statistical study of local magnetic anomalies, by Victor Vacquier and James Affleck; (4) A comparison of two sets of transcontinental magnetic data, by G. P. Woollard; (5) Geomagnetism and the aurora, by C. W. Gartlein; (6) Ionospheric observations at the 1940 eclipse in Brazil, by T. R. Gilliland; (7) Diurnal variation in electrical resistance of the vertical column of the atmosphere at Watheroo, Western Australia, by G. R. Wait and O. W. Torreson; (8) The production of neutrons by the cosmic radiation, by S. A. Korff; (9) Attempted identification of the solar *M*-regions, by R. S. Richardson; (10) Diurnal and seasonal variations in radio reception at broadcast frequencies during the last sunspot-cycle, by H. T. Stetson.

Other papers of interest to readers of the JOURNAL were the following: Origin of New Jersey magnetite deposits, by Donald M. Fraser, Gravity measurements in Guatemala, by F. E. Wright, and Geomagnetic survey of the volcanic areas of Guatemala, by A. G. McNish, presented at the session of the Section of Volcanology; Errors in measurements of condensation-nuclei, by O. H. Gish and Marcella Lindeman Phillips, presented before the Section of Meteorology.

On the evening of April 30, the third award of the Bowie Medal "for distinguished attainment and outstanding contribution to the advancement of research in fundamental geophysics" was made to Dr. J. A. Fleming with citation by Dr. L. H. Adams. This award was followed by the address of the retiring president of the Union, Dr. R. M. Field, on "Geophysics and world affairs." On the evening of May 1, the annual smoker was held in the Cosmos Club Auditorium at which a brief program of entertainment of interest to all was given.

The papers and reports will be published in the *Transactions of 1941* of the Union.

10. *American Section of International Scientific Radio Union*—The Executive Committee of the American Section of the International Scientific Radio Union decided to abandon plans for a joint meeting of that organization with the Institute of Radio Engineers in 1941. In view of that decision and of the general situation existing at the time, it was also decided that the annual Conference on Ionospheric Research usually held following the Radio Union's meetings at the Department of Terrestrial Magnetism of the Carnegie Institution of Washington should not take place.

THREE-HOUR-RANGE INDICES, *K*, FOR TWELVE MAGNETIC OBSERVATORIES, JANUARY TO JUNE, 1940

By H. F. Johnston

The Association of Terrestrial Magnetism and Electricity of the International Union of Geodesy and Geophysics passed a resolution in regard to three-hour-range indices at its Seventh Assembly held in Washington in September, 1939. The resolution was as follows: That the co-operation of magnetic observatories be sought for a three-year period in an international trial-scheme for the provision of three-hour-range indices (K) to characterize the variation in the degree of irregular magnetic activity throughout each day, especially in order to meet the requests made by the International Union of Scientific Radiotelegraphy and other bodies for information concerning the magnetic activity more detailed than the present daily magnetic character-figures, and that this trial-scheme should, for the period 1940 to 1942, replace the scheme for a numerical character-figure.

In response to the circular letter of January 20, 1940, from Dr. J. A. Fleming, President of the Association of Terrestrial Magnetism and Electricity, 19 magnetic observatories are supplying indices beginning January 1, 1940. The indices from seven observatories for 1940 were published[1] in the issue for March, 1941, of this Journal. Those from the other 12 observatories for the period January to June, 1940, appear herewith. The principles and practice of scaling K are described in the paper[2] entitled "The three-hour-range index measuring geomagnetic activity."

The list of contributing observatories is given in Table 1. The follow-

Table 1—*Contributing observatories*

Abbreviation	Observatory	ϕ	λ	Φ	Ψ	Lower limit, $K=9$
		°	°	°	°	γ
Le	Lerwick	60.1	1.2 W	62.5	−23.6	1000
Do	Dombås	62.1	9.1 E	62.3	−23.6	750
Me	Meanook	54.6	113.3 W	61.8	+17.2	1500
Si	Sitka	57.0	135.3 W	60.0	+21.4	1000
Es	Eskdalemuir	55.3	3.2 W	58.5	−20.4	750
RS	Rude Skov	55.8	12.4 E	55.8	−20.6	600
Ag	Agincourt	43.8	79.3 W	55.0	+ 3.6	600
Wi	Witteveen	52.8	6.7 E	54.2	−19.3	500
Ab	Abinger	51.2	0.4 W	54.0	−18.4	500
Ni	Niemegk	52.1	12.7 E	52.2	−18.8	500
Ch	Cheltenham	38.7	76.8 W	50.1	+ 2.4	500
SF	San Fernando	36.5	6.2 W	41.0	−13.6	350
Tu	Tucson	32.2	110.8 W	40.4	+10.1	350
SJ	San Juan	18.4	66.1 W	29.9	− 0.7	300
Ho	Honolulu	21.3	158.1 W	21.1	+12.3	300
ZS	Zo-Sè	31.1	121.2 E	19.8	+ 2.2	300
Hu	Huancayo	−12.0	75.3 W	− 0.6	+ 1.3	600
CT	Cape Town	−33.9	18.5 E	−32.7	−13.7	300
Wa	Watheroo	−30.3	115.9 E	−41.8	+ 1.3	350

[1]Terr. Mag., **46**, 95-117 (1941).
[2]Terr. Mag., **44**, 411-454 (1939).

ing information is given for each observatory, the abbreviation for name of the observatory, the geographic latitude (ϕ) and longitude (λ), the geomagnetic latitude (Φ), the angle (Ψ) (positive east from geomagnetic north) between the geomagnetic dipole meridian and the astronomical meridian, and the lower limit of the range for K-index of 9. The observatories are arranged in order of geomagnetic latitude. The scale for K

TABLE 2—*Lower limits of ranges R for three-hour-range indices K*

Observatory	For value of K									
	0	1	2	3	4	5	6	7	8	9
	γ	γ	γ	γ	γ	γ	γ	γ	γ	γ
SJ, Ho, ZS, CT......	0	3	6	12	24	40	70	120	200	300
SF, Tu, Wa..........	0	4	8	16	30	50	85	140	230	350
Wi, Ab, Ni, Ch.......	0	5	10	20	40	70	120	200	330	500
RS, Ag, Hu..........	0	6	12	24	48	85	145	240	400	600
Do, Es..............	0	8	15	30	60	105	180	300	500	750
Le, Si...............	0	10	20	40	80	140	240	400	660	1000
Me..................	0	15	30	60	120	210	360	600	1000	1500
Optional.............	0	20	40	80	160	280	480	800	1350	2000
Optional.............	0	30	60	120	240	420	720	1200	2000	3000

at each observatory was adopted in accordance with the method outlined in paragraph 9 of the previously mentioned paper. The lower limit of the gamma-ranges for K-indices, 0 to 9, for each observatory is tabulated in Table 2. Preliminary advice on the ranges encountered at the magnetic observatory established by the United States Antarctic Expedition in Antarctica, 1940-41, indicates its lower limit for a K-index of 9 must be at least 3000 gammas.

The eight indices for successive three-hour periods of the Greenwich day as reported by each observatory are given in Table 3.

The frequency of occurrences of the K-indices for each observatory is given in Table 4. In general, the ideal of frequency-distributions of K for all observatories has been reasonably approached. The average number of intervals for disturbed conditions ($K=5$ to 9) where the K-in-

TABLE 4—*Frequencies of K-indices, January to June 1940 (1456 3-hour intervals)*

K index	Observatory																		
	Le	Do	Me	Si	Es	RS	Ag	Wi	Ab	Ni	Ch	SF	Tu	SJ	Ho	ZS	Hu	CT	Wa
0	160	356	306	261	48	227	194	170	16	164	167	118	186	288	330	34	152	338	186
1	362	216	349	343	328	330	282	274	325	376	324	262	338	421	421	164	329	360	420
2	398	326	278	332	509	344	396	398	445	399	373	351	406	387	339	478	436	379	441
3	289	283	232	242	341	298	317	333	378	264	338	387	295	215	233	488	307	244	245
4	129	128	113	125	135	148	125	168	182	157	151	202	128	85	77	177	136	71	93
5	45	58	72	72	45	53	72	62	59	46	52	87	61	29	30	71	51	37	30
6	27	28	60	29	18	22	27	26	24	29	23	29	23	22	16	28	30	17	18
7	16	25	40	24	18	19	30	17	18	14	14	16	11	6	8	13	8	7	7
8	15	22	5	13	5	3	11	5	5	3	10	3	8	2	2	3	5	2	9
9	15	14	1	15	9	12	2	3	4	4	4	1	...	1	...	...	2	1	1

January 1940

	1	2	3	4	5	6	7	8
Le	2111 2233	4322 2104	2322 3864	3112 3454	2311 1113	3322 3353	3111 3335	2321 2123
Do	3202 2234	4301 3005	2321 3974	3323 3645	2100 0003	2332 3463	1010 4345	2121 3223
Me	0121 1212	3444 2101	1356 7742	2335 4523	3510 0011	3334 4432	2223 5223	3420 1111
Es	2222 2133	3322 2114	1432 4764	2113 3555	2410 1123	3323 3453	3122 4235	2321 3223
RS	3212 2233	4311 3205	1332 5865	2013 5654	2421 0013	3323 3453	3122 4335	3331 2224
Ag	2221 2222	2422 3222	2334 5742	2421 3433	1510 0222	4423 3332	4222 3324	3420 1212
Wi	2222 2233	4332 3214	2332 3655	2013 4545	2412 1233	3332 3463	3222 4345	2421 3333
Ab	3212 3243	4322 2214	2422 4754	3213 4555	2422 1123	3333 4453	3222 4345	3432 3333
Ni	3202 2213	4211 3115	2322 5755	3113 4654	2421 0013	3323 3453	4222 4345	3331 1223
SF	2222 2143	4331 2314	2232 2344	3112 3554	2324 1133	2322 3454	4122 5135	3322 1333
ZS	3122 2324	4233 4322	3343 5754	2323 5542	3321 1113	3433 4533	3323 4432	2430 3321
CT	1223 1231	2213 3212	2123 5743	2334 4333	2202 2121	1323 4342	2112 3424	1222 2121
	9	10	11	12	13	14	15	16
Le	2011 2352	2111 6654	3233 2256	4332 3345	2222 2110	0000 0013	3201 1001	2222 2343
Do	3230 3462	4332 8765	2323 2256	0022 3445	0001 0020	2110 0012	3220 0001	2221 2443
Me	1013 3222	0313 7643	2466 4333	3563 5333	2223 1111	0013 1001	1121 1000	0054 3211
Es	2012 2352	2112 4554	2333 2254	3343 3445	2222 2110	0001 1122	3311 1112	2122 3332
RS	2011 2462	2112 5554	2233 3355	3332 3445	2322 2110	0001 0122	4201 2001	1222 3443
Ag	1112 2232	2301 5432	2533 2343	3452 3323	1321 2110	0002 1111	3201 2011	2141 3222
Wi	2111 2464	2113 6554	3223 2365	4332 3445	2222 2110	0002 2022	4302 2112	2222 3453
Ab	1122 3453	2222 5555	2333 3265	3343 4445	2332 2121	1111 1123	4211 1213	2222 3343
Ni	2011 3462	2212 6554	2323 2464	3322 4445	2322 2120	0011 0122	4202 2112	2122 3443
SF	3001 3454	3013 7565	1332 3464	3343 3435	2333 0010	0003 1034	4110 1003	2123 3332
ZS	2223 3433	2223 6542	4342 4454	3433 5424	2222 2222	3323 2223	3413 3323	4234 3332
CT	2212 3243	2124 6353	2244 3244	2333 3323	1121 0100	0023 2000	2103 2212	3133 4222
	17	18	19	20	21	22	23	24
Le	3321 4344	3223 4763	2122 1211	1111 2230	0000 0100	0011 0331	0011 0133	3311 2343
Do	3111 3354	1103 4773	0022 1220	1100 2240	0010 0200	0000 0440	0001 2133	3301 2354
Me	2232 6432	1153 6552	3103 2112	0122 2211	0001 0001	0002 2222	0134 1011	0223 4333
Es	3332 4343	2234 4752	2122 2321	1111 2331	1011 2210	0112 1331	0012 2132	3322 2343
RS	3232 4343	3223 4772	2011 1221	1110 2241	0000 1210	0111 0441	0012 1133	3312 2353
Ag	3231 4433	2232 4432	2001 2212	0221 2221	0001 1111	0212 0221	0122 2121	2322 2232
Wi	3333 5444	3224 4773	2111 2232	1202 2342	1012 2222	1112 1442	1012 2134	3321 3354
Ab	4332 5343	2333 4762	3122 2221	2222 2241	1111 1210	1112 1331	1122 2233	3322 3343
Ni	3322 5344	2224 5663	2011 1221	1111 1241	0011 1210	0112 1431	0012 2232	3312 2353
SF	4333 4544	2345 5773	3123 2130	0101 1231	0002 3120	0112 1440	1023 2243	3232 0454
ZS	1333 5533	2324 4543	4323 3232	3322 4332	2212 2211	3323 3433	3343 3222	3223 3443
CT	2143 5433	1024 5653	3011 3121	1332 2210	0023 1200	0222 1330	2132 2132	1223 3332
	25	26	27	28	29	30	31	
Le	3321 3223	0001 0112	1011 1102	1010 0001	1110 2553	4322 3333	2222 3464	
Do	3210 2303	0000 0003	0020 1101	1000 0002	0000 0532	3322 2333	3222 3455	
Me	2343 4210	0000 0000	0230 0000	0000 0000	0012 3321	3344 3222	2443 6443	
Es	3332 3313	0001 1122	1122 2112	2010 1111	2111 2343	3323 3332	3333 4454	
RS	3331 3303	0000 0112	1121 1111	1010 0012	0100 2433	3322 2433	2333 4454	
Ag	3331 4321	0000 0211	1330 1110	0110 0112	0112 3331	3234 3332	2242 5445	
Wi	3332 4313	0001 1122	0110 1002	1000 0012	2101 3543	4423 2433	2333 4555	
Ab	3332 4313	1111 1222	2221 1212	2111 1111	2111 2443	3323 3433	3333 4454	
Ni	3321 4313	0001 1022	1121 1212	2100 0012	1100 2443	3322 2433	3322 4554	
SF	4322 5323	1112 1322	1233 3311	1021 0222	1203 0453	3243 4443	2443 4655	
ZS	1243 4423	2231 1131	3233 3221	3222 0223	2333 3343	5355 5433	3333 5534	
CT	1243 4200	0013 1122	0220 1110	1023 3000	1002 2442	3233 3433	3234 5443	

February 1940

	1	2	3	4	5	6	7	8
Le	4333 3585	5232 3343	3112 3434	1011 1433	2111 3324	3122 2244	4212 2222	3212 1133
Do	3233 4585	5102 3436	3102 3436	2001 0543	2101 3224	3012 3254	4211 3222	2112 0243
Me	4376 5443	3353 3221	1033 3311	0100 1211	1123 3301	1122 2223	3112 4311	2234 1112
Es	4333 4554	3233 3343	3122 3435	1111 1233	3112 3324	3222 3243	4222 2222	2222 2233
RS	4433 4554	4232 2343	3112 3535	1010 0544	3102 3334	3123 3253	4212 3222	3222 1143
Ag	4454 5335	4343 2222	4032 2332	0100 1311	2012 2103	2132 2123	2100 2222	2221 1132
Wi	5334 4654	3223 3352	2113 3535	1112 1433	2112 4324	4123 3354	4212 3232	2222 2243
Ab	4333 5655	3233 3443	3222 3545	1111 1433	3122 4434	4222 3354	4222 3232	3222 2243
Ni	4433 4555	3232 2443	3212 4535	1111 1543	2112 3334	4112 3254	4322 4222	3222 2243
SF	5345 4545	4233 3422	3113 4425	2122 2324	3112 4445	4223 3343	5112 2223	3211 2343
ZS	4244 5443	2334 4332	2233 4523	2211 2433	1323 4322	2234 4433	4322 4323	3322 2433
CT	3223 3433	2034 4312	2221 3433	0021 1232	2112 3322	2104 3133	4102 2112	3212 2322
	9	10	11	12	13	14	15	16
Le	3322 1103	3211 1133	1012 2134	4322 3422	3111 2144	3112 1002	2112 2112	2112 1232
Do	3321 1003	2100 0234	0002 1145	3322 3621	3010 2153	2002 1002	2102 3112	1002 1133
Me	4331 1101	0000 0112	1103 2123	2323 5421	1122 3111	1104 2001	1024 4010	0213 0111
Es	3321 1203	2211 1233	2122 2243	3322 3322	3221 3132	2112 2111	3122 2222	1112 2333
RS	2322 1103	2101 0133	1012 1143	3422 3411	3111 2043	2112 1011	3112 3112	1122 2233
Ag	3310 0001	1000 1122	1001 1123	3331 2332	1210 2221	0001 0001	2012 2020	0201 1221
Wi	3311 2213	2211 2234	1123 3244	4322 4421	3222 3143	2213 2002	2013 3112	0112 2333
Ab	3322 2213	2211 1233	2112 3243	3322 4422	3222 3243	2212 2112	2123 3222	2212 1333
Ni	3312 1103	2101 0233	1112 1143	3422 3422	3111 2143	2112 2111	2112 3122	1122 2333
SF	2311 0303	3011 1233	3121 3233	3213 4521	3222 3231	3113 1202	3123 3221	1222 1423
ZS	2232 1211	3322 1333	4234 3133	3322 5533	3222 3232	3234 2102	1233 3322	2233 2312
CT	2101 0001	1102 1222	1113 2033	1102 3432	2132 2222	1112 0100	1123 3310	0132 2222
	17	18	19	20	21	22	23	24
Le	0112 1200	0001 1010	0000 0012	5421 2333	4322 3322	3232 2223	2211 2133	4222 2223
Do	0001 1200	0000 0000	0000 0001	4411 2233	4322 3313	4321 2333	2221 2233	4101 2334
Me	0013 3110	0010 0000	0001 0001	5441 2322	2345 5311	1353 3211	2322 1022	4332 2203
Es	1122 2311	0011 1111	1001 1112	3332 3332	4322 3412	3232 2223	2221 2133	4222 2334
RS	0002 0200	0000 0010	0001 0101	4432 2333	3322 3322	3331 2323	2212 1133	4222 2234
Ag	0122 2110	0110 0210	0000 1212	4431 3332	5313 3222	2452 3212	3321 2325	5332 2214
Wi	0012 1211	0000 0010	0001 0001	4332 2333	4323 3422	4332 2223	3321 2234	4332 3334
Ab	1122 2321	1111 1122	1111 1212	4332 3333	4332 3522	4332 2333	2221 2133	4232 2334
Ni	1112 2211	0100 0110	1001 0112	4422 2343	3312 3422	3232 2333	2112 1134	4212 3234
SF	0132 1320	0003 1321	1033 1313	4442 2333	3232 2531	2242 1334	2233 1133	3212 2335
ZS	2333 2311	2320 1113	3322 1223	5342 4332	3224 5322	2233 3332	2222 2234	3323 2213
CT	0121 0011	0110 1100	0021 2201	3333 3123	2113 2331	1122 2022	0011 1223	1212 3113
	25	26	27	28	29			
Le	3443 5551	1011 2243	2321 2111	1111 1113	2223 2422			
Do	3433 6561	0210 2243	1320 2110	1111 1204	2232 3521			
Me	4577 6532	1200 1231	0301 1100	0102 1001	0222 3320			
Es	4344 4442	2121 2243	2322 2111	1212 2123	2222 3332			
RS	4343 5442	1011 1243	2321 2000	1211 1124	1232 3532			
Ag	4526 4533	1000 2221	2400 2010	0112 1111	0330 3322			
Wi	5544 4552	1012 2353	2223 2011	1113 2224	1223 3432			
Ab	4343 5553	2121 2243	3321 2111	1112 2123	2223 3433			
Ni	4433 4453	2121 2343	2321 2111	1211 2124	2222 2532			
SF	3544 5563	3133 1242	3432 3102	1220 1233	2243 3423			
ZS	4555 5553	3322 2333	3322 2112	3233 2313	3234 4422			
CT	3334 5453	2131 3220	1322 3100	0102 2021	1223 4322			

¨Interpolated

Table 3--Three-hour-range indices, K, January to June 1940--continued

March 1940

	1	2	3	4	5	6	7	8
Le	0222 2110	1111 1112	1221 1223	0001 2013	2111 1000	0001 0111	1100 1111	2221 1144
Do	0222 2210	1100 0102	0021 0223	0000 2112	1021 0000	0000 0101	1000 1002	2200 0045
Me	1332 2000	0201 1000	0213 0102	0000 2000	0102 1000	0000 0001	0001 2001	1222 1013
Es	1222 2210	2111 1222	2221 2213	1111 2113	2121 2001	0001 1222	2211 2112	2222 2144
RS	0232 2220	1111 1112	1221 0223	0000 2013	1022 0000	0000 1111	1100 1101	2221 1144
Ag	0321 1110	1211 0211	2212 1112	0200 1212	1302 2000	0010 1121	1200 2111	3231 1035
W1	1332 2220	2112 2212	2122 2223	1011 1113	2211 1100	0001 1111	1101 1111	3321 1145
Ab	1322 2211	2111 1122	2221 2223	0110 2113	1221 1111	1111 0222	2211 2222	2221 2144
N1	1212 1210	2111 1212	2221 1223	0000 1113	1121 0101	0000 0111	1201 1111	2211 1144
SF	1342 3111	1212 2010	2232 2322	1112 2113	2213 3000	0010 2023	2322 1111	3323 1153
ZS	3423 3211	2212 2221	1322 1222	2122 2002	1332 1000	1212 1233	2311 2223	2232 2224
CT	0033 3000	0211 0110	0201 1222	0011 2102	2001 1000	0101 0122	2211 1001	2211 1033
	9	10	11	12	13	14	15	16
Le	5631 2223	2121 1122	1010 1110	0001 1466	4312 2213	2122 1232	0001 0000	0011 1133
Do	6511 2223	0000 0022	0000 0210	0000 0478	4211 2203	0212 2231	0000 0000	0000 2033
Me	5655 3111	1223 2100	1000 1100	0000 1224	3244 2102	0566 0111	0000 0000	1031 1010
Es	4532 2232	2221 2122	1111 1211	0011 2355	3222 2213	2222 2332	0001 1101	1111 2132
RS	4532 1223	1121 1112	0010 1110	0001 1445	3212 1203	1112 1232	0000 0000	0001 2033
Ag	6743 2222	2122 0110	1000 1110	0010 1224	4232 2212	2344 1112	0000 0000	0131 0021
W1	5431 2333	3333 3222	1110 1010	0001 1455	3332 1313	2232 1232	0001 1100	0012 1243
Ab	4521 2332	2222 2222	2111 1221	1111 1455	3322 2313	2232 2233	1102 3101	1111 3233
N1	4511 1222	2101 1122	1001 0110	0001 1445	3211 1303	1212 1232	1001 1000	0001 2133
SF	4512 1233	1132 1112	1221 1120	0023 0546	4321 3303	2233 0333	0111 2101	1012 1243
ZS	4323 2322	0223 2121	2211 2221	1212 3533	4433 2312	2343 2322	3402 1103	2422 1333
CT	3132 1100	0102 2211	0122 0000	0002 1535	3222 2201	0023 0111	1003 1000	0100 1332
	17	18	19	20	21	22	23	24
Le	1001 0000	0000 1000	2222 3565	4433 4244	4321 2233	3312 1243	0244 4459	7543 7999
Do	2000 0000	0000 0000	1112 2675	5423 3354	4311 2243	3101 1144	0034 4359	9543 7888
Me	1011 0000	0000 0000	0244 3333	4555 4333	2212 3311	2120 0022	1356 4336	5776 8986
Es	2112 1110	0011 1011	2233 3443	4334 4344	3221 2223	3212 2244	1235 4447	6433 7999
RS	0000 0000	0000 0000	1121 3453	4333 3445	3311 2233	3211 1144	0145 4456	5443 6999
Ag	1000 0000	0100 0000	2244 2444	5534 3333	3311 2222	4221 1123	0456 4447	6754 7896
W1	2101 0000	0000 0000	1222 3444	4444 3254	3322 2232	2322 2143	2234 3456	6444 6998
Ab	2121 1101	0011 1111	2222 3443	4323 4345	4332 2233	3322 2244	1145 3456	6333 6999
N1	1111 0000	0000 0100	2212 2443	4423 4344	4311 1232	3211 1144	0144 3456	5323 6998
SF	1132 3201	0033 3201	2324 3452	4324 4445	5312 1313	4333 1043	0254 2446	5333 4897
ZS	3432 2003	2322 0112	3335 5433	3435 4334	2522 2224	3422 1234	3466 3326	4345 7876
CT	0001 0000	0000 0100	1234 5541	4233 3334	4132 3221	2233 2232	1235 3335	4323 5987
	25	26	27	28	29	30	31	
Le	9988 5359	7642 2363	6534 3334	6332 3233	3224 5879	9977 6876	8437 8869	
Do	8877 6478	8652 2363	7534 3435	6322 3343	3123 4967	8877 7788	9337 9869	
Me	7787 7457	5743 2333	6534 3223	6434 4212	2116 6766	7787 6844	6777 7655	
Es	9988 6457	6433 3363	5434 3434	5333 3343	3224 4978	9977 6775	6348 7856	
RS	9998 6369	7442 3363	5434 2435	4333 2333	2124 3989	9977 6776	7347 7756	
Ag	9677 7478	8762 2352	5523 2343	5433 3233	2124 4878	8786 7655	7657 7755	
W1	8777 5567	6432 2372	4433 2335	4322 2343	3123 4878	7776 6775	5438 6755	
Ab	9777 6467	6443 3463	5444 3434	4333 3343	2224 4868	7876 6775	6448 7755	
N1	9768 5367	6442 1362	5433 2435	3322 2233	3123 4767	7864 5675	6337 6655	
SF	7678 6366	4432 3443	5443 3414	5422 2243	4114 5757	7865 5565	5235 6555	
ZS	8768 6365	4433 3343	5443 3312	3333 4323	3334 6776	7665 7655	6457 6644	
CT	8666 5366	6331 2352	4333 3214	3223 2232	3024 4767	5676 4565	5427 5455	

April 1940

	1	2	3	4	5	6	7	8
Le	8745 3444	2122 1287	9964 5474	2222 3333	2211 0233	3221 0122	0011 1110	0011 1210
Do	8764 4444	2211 2398	9974 5585	3223 2333	2221 1332	4222 1122	0001 1011	0011 0210
Me	6777 6433	2232 2365	7775 5442	2246 2222	2444 1211	1323 0021	0000 0011	0011 0100
Es	6545 4544	2222 2366	7754 5554	3222 3333	2222 1233	3221 1121	1011 2121	0012 2311
RS	6545 4444	1111 2365	7663 4463	2223 3443	3211 1333	4321 1022	0000 1010	0101 1220
Ag	6666 4543	3332 2466	8775 4554	4244 2233	3532 1222	4411 1131	0000 1121	0000 1201
W1	5445 3445	1112 2265	6663 4563	3123 3343	2211 1333	3221 1032	0000 1110	0011 1210
Ab	5554 4544	2222 3365	7754 4554	3223 3434	3223 1333	3233 2132	1011 2121	1122 1311
N1	6544 3444	2201 1265	6643 4563	3222 2333	2211 1332	4211 1122	1001 1011	0011 0210
SF	1122 3466	7654 1265	7554 5564	4234 2433	3323 3344	4334 0140	1012 2110	0121 1310
ZS	4555 5442	2312 2355	7665 5563	3344 4433	3123 1213	5232 3132	2122 2132	1222 1221
CT	5434 3333	1032 0254	5652 5343	3233 3123	2222 2122	3211 2020	0011 2120	1213 2210
	9	10	11	12	13	14	15	16
Le	1001 2100	1001 1000	0001 2210	0112 1100	2212 3311	1222 2312	2222 4434	3322 2333
Do	1000 0000	0000 0000	0000 3320	0111 1101	3012 4311	1222 2321	2102 5544	4432 2234
Me	0010 0100	0110 0001	0012 2110	0001 0001	1214 3212	1465 2211	1235 3413	2431 0111
Es	1112 2210	1012 2111	1112 3311	1112 2211	2223 3421	1332 2322	2222 4333	4322 2233
RS	1101 0000	1001 0000	0000 2310	0211 2100	2213 3411	1222 1222	2222 3343	3332 2244
Ag	1001 1111	0000 0211	0112 2212	0010 0111	2323 3322	2443 2322	2334 3433	3532 1233
W1	1000 0100	0000 0000	0002 2300	0111 2100	2223 3311	1232 2223	3332 3342	4433 2243
Ab	2112 1111	1101 2112	1111 3311	1211 2211	2222 3422	2332 2322	2222 4433	4322 3233
N1	2100 0100	1000 0001	0100 2311	1111 0101	3112 3411	1222 2221	2102 3343	3322 2234
SF	1013 3101	1000 2011	1124 3232	0020 1101	3224 3422	2333 3322	1222 4434	4213 2334
ZS	2332 2011	2000 1011	1232 3322	2332 2110	2444 4422	2233 3222	2213 4432	2333 3233
CT	0122 1000	0011 0001	0000 1211	1112 1001	2113 3311	1212 2211	0012 3433	3112 1102
	17	18	19	20	21	22	23	24
Le	2320 2221	2010 1101	2121 1310	0231 2222	2222 1124	3332 3421	2211 2113	3011 3310
Do	3321 1121	1000 1000	3100 2310	0221 2223	3221 2133	3222 3420	3000 3014	3100 3200
Me	1111 1001	1331 0100	1210 1200	0222 2111	3222 1113	1574 4311	3000 3122	3002 3211
Es	3322 2221	2121 1112	2221 2321	1232 3332	3223 2233	3432 3421	2121 3123	3112 3311
RS	2321 1111	1020 1001	2111 2310	0232 2222	3222 2223	3332 2411	3111 2023	4111 3210
Ag	4431 1321	1111 1012	2210 2331	1231 2333	4332 2223	2353 3332	3002 3233	3103 3222
W1	2332 1111	2221 1102	3322 2220	0233 3332	4333 2234	3453 3421	2220 3334	4112 3211
Ab	3321 2221	2111 2112	2211 2311	1232 3333	4332 2233	3432 3422	3112 3223	3112 3311
N1	3221 1121	1111 1002	1111 1321	0232 3332	3221 2223	3332 2421	3101 2023	3001 3211
SF	3221 1201	3011 1222	3111 1311	1222 3433	4342 1134	3442 2212	4133 3334	4113 2221
ZS	3432 1112	3322 1102	1131 2222	2343 3453	5444 2233	3433 4311	3332 3023	2223 3122
CT	1001 0000	1011 0101	1121 1000	0223 3232	3333 2233	1323 1122	2000 2013	0010 3200
	25	26	27	28	29	30		
Le	3942 2588	8643 3354	4221 3333	3111 3323	4321 2210	0222 3333		
Do	3932 3597	8643 4364	4202 3332	2102 3312	5321 2220	0202 3332		
Me	3662 1454	6556 6543	4333 2110	1105 4212	4435 3211	0025 2312		
Es	3732 3566	7433 3342	3221 2332	2121 2323	4322 3221	1223 3343		
RS	4731 3567	6432 4344	4220 2322	2122 2212	3321 2210	0222 4333		
Ag	4732 2477	8875 3454	4323 3223	4012 2324	4322 2221	1113 2333		
W1	4742 3556	5442 3344	5322 2322	2212 2222	3321 2110	0222 3333		
Ab	4732 3567	6432 4443	4321 2332	3222 2312	4322 3321	1212 4343		
N1	4721 2457	6322 3344	4311 1222	2112 2312	3321 2211	0212 3342		
SF	5733 2556	7442 3334	2322 1222	3133 4313	4321 1321	2213 3353		
ZS	5723 3445	4333 3433	3333 4312	3133 3222	3432 2221	3234 3234		
CT	4322 3566	3222 2232	2200 1102	2022 1002	3101 1210	1122 2322		

May 1940

	1	2	3	4	5	6	7	8
Le	2112 2332	2211 1220	2111 2111	2110 1112	2122 1122	0001 1000	1121 1221	2211 2111
Do	1001 3333	1100 1300	2021 2001	1000 1102	2012 2221	0000 0000	0121 1131	2200 2200
Me	2021 2221	1211 0100	1133 2101	2030 1101	0033 1111	0010 0010	1232 0112	1100 1011
Es	2111 3232	2211 1311	2121 2211	2111 1112	2112 2221	1001 2101	1221 2221	2211 2211
RS	2111 2232	0110 1210	1111 2001	2111 1111	2102 2122	0000 0000	1222 1211	1200 2001
Ag	2132 2232	3311 1321	2232 2222	3221 1212	1122 2131	1110 0200	0331 2222	3211 1222
Wi	2221 2232	2210 1200	2121 1101	2020 1103	3111 1111	0000 0100	1221 2210	2200 1111
Ab	2221 2332	1221 1221	2122 2111	2111 2113	2222 2222	1111 1100	1222 2222	2211 2211
Ni	2101 1232	1201 1210	1111 2101	2101 1112	2111 2222	0000 0000	1321 1111	2200 2111
SF	2121 3232	1303 3321	2132 1301	1121 1312	3224 2122	2000 3100	1220 1211	2303 3112
ZS	0322 2332	1232 1302	1233 3212	3222 1113	3223 2221	3122 1103	3432 2112	2322 2111
CT	2010 2131	1110 0100	0111 1101	0001 0002	2012 0001	0001 0000	0120 1001	1121 0001

	9	10	11	12	13	14	15	16
Le	3322 2321	1222 3344	3422 3232	3332 2334	3222 3343	3222 2322	1422 3333	4101 1220
Do	3303 3231	1113 4344	4332 2333	3323 3334	3302 3343	3223 3232	2322 2343	3100 0110
Me	1530 5211	1445 2323	4344 3212	3565 3213	3222 2122	3564 3221	2346 3313	4102 1210
Es	2323 3321	1322 4344	3322 3332	2332 3234	3212 3333	2232 3322	1332 3333	3211 2311
RS	3322 3221	1222 3344	3332 2243	2332 2334	3212 3343	3232 3222	0312 2443	3200 2121
Ag	2321 3322	1233 3333	5432 2223	3553 2323	2322 2343	3442 3232	3433 3334	3001 0212
Wi	2302 3322	1222 3344	3332 3242	2332 4334	3212 2343	4332 3322	1331 2344	4001 2222
Ab	3412 3422	2222 3344	3332 3342	3332 3334	3112 3343	2323. 3333	2332 3443	3101 2122
Ni	3302 3322	1222 3344	3322 2242	2322 2233	2212 2233	2212 2222	1312 2343	3100 0021
SF	3400 3311	2433 2435	4333 0343	2332 2223	2220 2433	3333 4423	2422 3433	3122 3312
ZS	2432 4322	2333 2334	2323 4223	2243 3312	2332 2233	3233 3313	3332 4443	3221 1022
CT	1212 3210	0112 2224	3211 0231	1201 0013	1210 1121	1012 2111	0332 2011	1000 2001

	17	18	19	20	21	22	23	24
Le	2222 2333	4444 4331	4222 1324	1221 3431	1421 1123	5554 3222	1222 2443	2756 5564
Do	2102 2343	5444 5432	4222 3324	2222 4420	1411 0021	5555 3321	2201 1154	2757 5564
Me	2322 1221	3365 6322	1233 2310	3311 4320	2401 1121	3776 4322	1221 1342	5677 6544
Es	2223 2332	4453 4332	3122 2324	2222 3421	1311 2222	4553 3321	2222 2552	2647 5554
RS	2223 1343	4544 5322	4122 1213	2211 3410	2410 0123	4444 3321	2302 1552	3657 6454
Ag	2332 2333	5576 5333	3223 2233	2322 3331	1520 1232	5674 2333	1323 1354	3766 5455
Wi	1223 2343	3444 5322	3233 1323	1211 3320	2410 0132	4444 3321	2321 1553	3647 5444
Ab	2323 3443	4454 5332	4122 2324	2323 3421	2411 1233	4554 3331	2312 2653	3647 5454
Ni	2213 2342	4443 5322	4111 2213	2212 3420	1410 0122	4434 3321	2202 1253	3647 5454
SF	4344 3242	4453 5433	5124 3224	2232 4420	1432 1333	5533 3431	2243 1654	3666 4465
ZS	3332 3223	3564 5322	3233 2112	3333 3322	3422 1021	5445 3232	3333 2553	3665 6444
CT	2112 2231	3232 4321	3111 0004	0000 1210	0122 0002	3423 3210	0001 0342	1445 5354

	25	26	27	28	29	30	31
Le	4411 2332	3332 2446	7423 2334	3433 3323	3212 1321	1012 1222	1111 2101
Do	5400 2421	3432 3447	8323 3334	3433 3333	3221 1331	0000 2221	1000 0101
Me	4311 2222	3655 2335	6433 2224	4544 3212	3322 2122	0000 1111	1021 1011
Es	3312 2432	3332 2544	5323 2334	2323 4333	2212 2331	1012 2222	1211 2101
RS	4311 2431	2322 3445	5322 1324	1433 3322	3211 1221	1000 1111	1000 1000
Ag	5312 2333	3544 2345	5531 2234	4643 3233	3221 2333	0011 1122	2020 1211
Wi	3221 1542	2432 2554	5322 1334	3434 3332	2232 2431	0000 0222	1100 1100
Ab	4311 2433	3432 3544	5323 2334	2433 3333	3211 2332	1111 2222	1111 2111
Ni	4201 1432	3321 3444	5313 1224	2433 3322	3211 1321	0000 1222	1000 1001
SF	4401 2443	4433 5554	4322 2224	3433 4322	3223 1221	1012 1021	1232 0100
ZS	3312 2223	3443 4444	2432 2313	3343 3122	3332 2233	2221 1121	2222 0012
CT	2221 2231	2221 1434	3232 1113	1231 0121	2110 1010	0000 1011	1100 0000

June 1940

	1	2	3	4	5	6	7	8
Le	1001 1122	2221 3313	1101 3222	2111 1111	1122 2223	4444 3446	6544 3335	4322 3334
Do	0002 2123	1202 3313	1000 4321	2000 1200	1122 2213	4644 4435	6433 4335	5322 4434
Me	0010 1111	1231 2222	1002 2222	2000 1100	2131 1223	5776 6344	5666 5325	5344 3233
Es	1122 2222	2222 3322	1111 3322	2111 2211	1123 2224	4444 4434	4444 4333	4322 3443
RS	0112 2121	1211 3312	0101 4222	2001 1111	1133 3123	4434 4433	4444 4334	3322 3343
Ag	2020 1122	1332 3323	0011 3332	2011 0211	1132 1224	5756 4344	5635 3335	4333 3344
Wi	0111 1222	1311 3212	0122 3221	2111 2111	1223 4333	4433 4434	3444 4333	4333 3344
Ab	1122 3122	2322 3322	1112 4332	2111 1111	2131 3334	4444 4433	5534 4334	4323 3444
Ni	1112 1122	2311 2312	1111 4222	3100 1111	1131 2224	4433 4433	4433 3334	4332 3444
SF	0112 3322	2210 4322	1012 4330	2132 3232	1234 4235	4353 4324	6544 4345	5223 3444
ZS	2222 2121	2432 3410	2222 3223	2233 2222	2343 3334	3343 4324	4534 4334	3332 3322
CT	0000 1021	1101 1102	0121 2000	1001 1000	0021 1123	3122 1322	5423 3233	3212 2234

	9	10	11	12	13	14	15	16
Le	2333 2333	3221 1011	2012 2212	1011 2221	0011 1222	1232 4567	4543 4521	4333 3233
Do	2422 3342	3121 1002	3001 2302	0000 3222	0000 2222	0102 4658	6534 4532	4222 3233
Me	1366 2323	4130 1012	1001 1101	2000 1121	0000 0113	1144 3445	5666 4321	3265 3232
Es	2333 2343	2121 1112	2121 2212	1022 3322	1111 2222	1232 5655	3443 4432	3233 3233
RS	1332 2343	3221 1002	2011 1201	1000 3221	0110 2112	1233 4556	5543 4431	3222 2233
Ag	2445 2343	3130 0122	2101 0212	1001 2233	0001 1223	1353 4565	5654 3320	5244 2243
Wi	2334 3242	2332 2101	1012 3302	0100 2121	1101 1222	1233 5545	4454 3332	3343 3222
Ab	2333 3443	3231 1112	2112 1312	1101 3322	1111 2222	2333 5645	4443 4432	3233 3333
Ni	2322 2343	3121 1112	2111 1212	1010 2222	0100 1222	1233 4656	4433 4431	3222 3223
SF	2233 3343	3213 2211	2112 2121	2201 2333	1003 3122	2243 4655	3555 2432	3332 3224
ZS	2433 2223	3331 1112	2232 2112	2332 2333	2221 2122	1344 3664	3534 3222	3343 2222
CT	0113 3232	1010 0001	1011 1001	1000 0121	0001 1001	0121 3535	2422 2321	2231 2212

	17	18	19	20	21	22	23	24
Le	3333 3432	2442 2221	2232 3322	2111 2101	2212 1011	0113 3212	4312 2222	3232 3345
Do	3233 4432	3342 3222	1323 3412	2001 2110	0201 1111	0003 4222	4222 2232	3232 3345
Me	3464 3222	3675 2211	2345 4312	1111 1110	2121 1110	0203 3113	4101 1121	3330 3121
Es	2233 3422	2342 2221	2222 4411	1112 2221	2222 2111	1113 3222	3221 2222	3332 4344
RS	3333 3433	2343 2121	3332 3312	0101 1111	1211 1110	0003 4221	3311 1231	3332 3334
Ag	4453 2321	3544 2233	2332 3233	1100 0322	1111 1221	0213 3323	4211 2233	4532 4333
Wi	2233 3322	1322 2221	1322 3311	0200 1110	1212 2110	0103 4322	3311 0122	2232 2333
Ab	2333 3432	2343 2232	2332 4422	1211 2121	1311 2111	1104 4322	4111 2332	3333 4244
Ni	3312 4333	2342 2121	2322 3322	1100 1111	1211 1110	1103 3222	3111 1232	3322 3244
SF	4322 4343	2443 0332	2233 3421	1120 2221	1221 2120	0125 3322	4303 3223	3322 3345
ZS	3333 3332	2534 2222	2543 3223	3111 2111	2221 1012	2024 4323	3212 1222	3443 3233
CT	0212 2211	0232 2010	0211 2200	0100 0000	0212 1100	0004 3222	3120 1012	2211 3334

	25	26	27	28	29	30
Le	4646 9875	5422 1543	2322 2311	2111 1431	0111 2131	5412 3332
Do	4847 9975	5423 2633	3223 3310	3001 1330	0200 2232	5302 2332
Me	4767 7755	3333 1332	3212 3210	3001 0210	0010 1121	4401 2312
Es	4646 9774	4322 2643	2223 3321	2122 2431	1211 2232	4311 3332
RS	5757 9774	5322 2643	2223 3300	2100 2430	0210 2232	5421 3321
Ag	3777 8665	4333 2444	3311 2222	3002 2231	1100 2132	4312 1333
Wi	4746 9664	4312 1663	2213 3400	2210 1421	0200 1232	4412 3321
Ab	5657 8664	4322 2644	2222 3321	3111 2431	1211 2242	4411 3332
Ni	4747 9764	5322 2643	2322 3310	2100 1430	0201 1242	4402 2331
SF	4657 7675	5432 3644	3103 1110	3220 1321	1210 1341	4412 3341
ZS	5667 7565	5334 2544	3333 2212	3211 1233	2220 1243	5322 2222
CT	3446 7553	3222 0322	1012 2100	1000 0011	0001 2120	2231 2122

..Interpolated

dex is most effective in describing geomagnetic activity due to corpuscular radiation is 149 for the four observatories whose geomagnetic latitude is 60° or greater, is 110 for the seven observatories whose geomagnetic latitudes are between 50° and 60°, and is 86 for the eight observatories whose geomagnetic latitudes are less than 50°.

The assistance of Miss E. Balsam in the preparation of Table 3 is gratefully acknowledged.

Department of Terrestrial Magnetism,
Carnegie Institution of Washington,
Washington, D. C., April 29, 1941

LETTERS TO EDITOR

(See also page 222)

IONOSPHERIC RECORDINGS DURING MAGNETIC STORM OF MARCH 1, 1941

Examination of automatic multifrequency ionospheric records obtained at the Kensington Experimental Station of the Department of Terrestrial Magnetism, Carnegie Institution of Washington, during the intense magnetic storm of March 1, 1941, reveals that the ionized regions of the Earth's outer atmosphere were greatly disturbed, and that the period of greatest disturbance corresponds to that of greatest magnetic activity.

Commencement of the ionospheric disturbance was associated with the development of an ionized region between the normal levels of the *E*- and *F*-regions. Virtual height of this region was 160 km at $06^h\,15^m$ GMT. By $06^h\,30^m$ its maximum ion-density had increased threefold and its virtual height had fallen to normal *E*-region levels at 130 km. Radio reflections from this region were returned by the normal process of magnetoionic double refraction. Both ordinary and extraordinary wave-components were recorded, and reflection-coefficients were not high. Apparently the condition was not one of simple sporadic *E*-region ionization.

Weak and highly-scattered *F*-region echoes were recorded from virtual heights at about 400 km through $09^h\,45^m$ GMT, although *F*-region maximum ion-density appeared to be about normal. From $09^h\,45^m$ through $10^h\,45^m$ the *F*-region was obliterated although weak and intermittent reflections from *E*-region levels were observed.

There appeared to be a slight recovery between $11^h\,00^m$ and $13^h\,30^m$ GMT, when both *E*- and *F*-regions were recorded. The maximum ion-density of the *E*-region as measured by the penetration-frequency was about normal, but ion-concentration in the *F*-region was about one-half of normal.

The interval between $13^h\,30^m$ and $18^h\,30^m$ was characterized by complete absence of radio reflections of any sort, except for occasional weak or intermittent *E*-region echoes recorded at wave-frequencies below 3.0 Mc/sec. It is significant to note that this period of greatest ionospheric disturbance closely coincides with the interval of most severe magnetic activity.

Between $18^h\,30^m$ and $20^h\,00^m$ GMT, ionospheric recordings exhibited a slight trend toward recovery, with occasional *E*- and *F*-region echoes being recorded. After $20^h\,00^m$ ionospheric conditions were rapidly returning to normal except for low *F*-region penetration-frequencies indicating an apparent deficiency of electrons in the upper region of the ionosphere. These low *F*-region penetration-frequencies persisted through

the night until about sunrise (11^h GMT), March 2, following which completely normal conditions were recorded.

The above comments give a general description of ionospheric conditions recorded at Kensington, Maryland, during the magnetic storm of March 1, 1941. It is anticipated that a more analytical report may be prepared for later publication.

Department of Terrestrial Magnetism,
Carnegie Institution of Washington,
Washington, D. C., April 25, 1941

H. W. Wells

SECULAR CHANGE AT CHELTENHAM, MARYLAND

It will be remembered that about 1933 a phenomenal change took place in the rate of secular change of declination at Cheltenham, Maryland. Within about a year the rate changed from an increase of 4 minutes per year to zero. This change of rate has persisted, the present rate being a few tenths of a minute per year, decreasing. (4′ per year means about 21γ per year)

Recently a larger and nearly as abrupt decrease has taken place in the rate of secular change of horizontal intensity. Determination of a rate of secular change for short periods is complicated by the annual variation, which has an amplitude of some 20γ. Plotting monthly means and drawing a smooth curve, the following were obtained as approximate rates of secular change (in gammas per year, decreasing) for the middles of consecutive years from 1933 to 1940: 54, 50, 47, 44, 41, 32, 21, 3.

U. S. Coast and Geodetic Survey,
Washington, D. C., May 14, 1941

H. Herbert Howe

CRITICAL FREQUENCIES AND VIRTUAL HEIGHTS OF THE IONOSPHERE, OBSERVED BY THE NATIONAL BUREAU OF STANDARDS AT WASHINGTON, D. C., JANUARY TO MARCH, 1941[1]

The following ionosphere data are in continuation of those published in each issue of the Journal since 1936.

The data given in Table 1 are similar to, but not the same as, those published in the form of graphs by the National Bureau of Standards each month in *Proceedings of the Institute of Radio Engineers*. The averages given there are for undisturbed days while those given here (Table 1) are for all days of the month. The midnight and noon values given for each day in Table 2 are equivalent to the Bureau's values given in code-form in the weekly Ursigrams issued by Science Service.

The data on critical frequencies give implicity the maximum ionization-densities of the ionosphere layers. The equivalent electron-density in electrons per cubic centimeter is 0.0124 times the square of the critical frequency in kilocycles per second.

[1]Report prepared by N. Smith and T. R. Gilliland.

TABLE 1—*Average virtual heights and critical frequencies, National Bureau of Standards, Washington, D. C.*
(Averages for all days of the month, including disturbed days)

January, 1941

EST	h_E	h_{F_1}	h_{F_2}	f^o_E	$f^o_{F_1}$	$f^o_{F_2}$
h	*km*	*km*	*km*	*Mc/sec*	*Mc/sec*	*Mc/sec*
00			293			3.05
01			296			2.91
02			295			2.84
03			296			2.78
04			287			2.95
05			288			2.91
06			288			2.93
07			270			3.38
08			225	2.04		5.85
09	120*	219*	228	2.52	3.51*	7.10
10	120	222	241	2.85	3.73	8.27
11	121	213	247	3.01	3.91	8.95
12	122	213	249	3.06	3.89	9.05
13	121	212	250	3.03	3.84	8.93
14	121	218	248	2.88	3.75	8.82
15	121*	224	242	2.69	3.56	8.61
16			229	2.31		8.10
17			225	1.78		7.41
18			236			6.41
19			243			5.44
20			258			4.34
21			278			3.74
22			285			3.34
23			294			3.14

February, 1941

EST	h_E	h_{F_1}	h_{F_2}	f^o_E	$f^o_{F_1}$	$f^o_{F_2}$
h	*km*	*km*	*km*	*Mc/sec*	*Mc/sec*	*Mc/sec*
00			300			3.31
01			301			3.30
02			299			3.21
03			296			3.13
04			290			2.98
05			291			2.71
06			290			2.54
07			253	1.60		3.96
08		234*	230	2.24	3.42*	5.89
09	120*	215	242	2.65	3.69	6.65
10	124	207	255	2.89	3.94	7.42
11	122	210	262	3.05	4.16	8.22
12	122	210	266	3.15	4.26	8.58
13	123	211	264	3.13	4.27	8.45
14	123	210	262	3.01	4.10	8.55
15	123	218	257	2.85	3.86	8.65
16	124*	226	244	2.58	3.58	8.45
17	130*		230	2.07		7.96
18			231	1.42*		7.23
19			241			6.23
20			247			5.13
21			269			4.22
22			280			3.85
23			294			3.58

March, 1941

EST	h_E	h_{F_1}	h_{F_2}	f^o_E	$f^o_{F_1}$	$f^o_{F_2}$
h	*km*	*km*	*km*	*Mc/sec*	*Mc/sec*	*Mc/sec*
00			308			3.46
01			309			3.09
02			312			2.88
03			311			2.60
04			312			2.44
05			317			2.18
06			308	1.54*		2.84
07	125*	255*	253	2.13	3.06*	4.67
08	130*	226	269	2.52	3.62	5.61
09	122	213	285	2.84	4.02	6.09
10	121	201	302	3.04	4.30	6.47
11	118	205	305	3.19	4.42	7.04
12	120	209	300	3.27	4.45	7.43
13	123	218	306	3.27	4.46	7.54
14	123	220	311	3.20	4.32	7.72
15	123	226	306	3.04	4.21	7.56
16	127	228	294	2.75	3.81	7.59
17	120*	244	261	2.38	3.31	7.34
18		330*	243	1.92	3.50*	7.17
19			240	1.10*		6.43
20			248			5.14
21			279			4.43
22			295			4.06
23			307			3.60

* = Less than ten days.

Table 2—*Midnight and noon critical frequencies for each day, National Bureau of Standards, Washington,*

Day	00 EST	12 EST			00 EST	12 EST			00 EST	12 EST		
	f^oF	f^oF_2	f^oF_1	f^oE	f^oF	f^oF_2	f^oF_1	f^oE	f^oF	f^oF_2	f^oF_1	
	Mc/sec	*Mc/sec*	*Mc/sec*	*Mc/sec*	*Mc/sec*	*Mc/sec*	*Mc/sec*	*Mc/sec*	*Mc/sec*	*Mc/sec*	*Mc/sec*	*M*
		January, 1941				*February, 1941*				*March, 1941*		
1	3.2	9.1	3.5	3.05	3.1	8.6	...	...	†4.3	†...	†...	†
2	3.0	8.0	..	3.05	2.9	8.6	NR	NR	†<1.7	†8.9	†4.3	†
3	2.1	9.3	3.9	...	2.8	8.7	NR	NR	†3.1	†6.8	†4.5	†
4	NR	NR	NR	NR	3.1	9.4	NR	NR	†3.0	†8.0	†...	†
5	NR	NR	NR	NR	3.7	8.4	4.1	3.2	†3.0	†7.3	†4.3	†
6	NR	10.4	3.6	3.0	4.7	9.7	4.1	3.15	†2.6	†6.9	†4.5	†
7	3.5	9.1	3.4	3.0	4.6	8.7	4.2	3.05	†2.4	7.5	4.5	.
8	3.3	9.2	3.4	3.0	3.3	8.7	4.3	3.1	3.6	9.1	4.4	3
9	3.7	10.7	3.6	3.05	3.1	8.9	4.2	3.05	3.7	8.2	4.5	3
10	3.7	9.1	3.7	3.1	2.6	9.1	4.2	3.1	3.9	7.4	4.5	3
11	3.2	8.9	3.9	3.1	3.0	9.2	4.3	3.05	3.8	7.9	4.4	3
12	2.3	8.5	3.9	3.05	2.8	†7.6	†3.8	†3.1	3.7	9.3	4.5	3
13	3.7	9.4	...	2.95	†3.8	†4.9	†4.0	†3.1	4.4	7.4	4.5	3
14	2.9	9.0	3.5	3.0	†3.4	†8.5	†3.9	†3.0	†3.3	†<3.9	†3.9	†3
15	3.6	9.6	3.9	3.0	†3.8	8.5	4.1	3.1	†2.1	†5.1	†4.2	†3
16	2.6	9.9	4.1	3.1	3.5	†7.2	†4.1	†3.1	†3.0	7.0	4.6	3
17	5.0	10.3	4.0	2.95	†3.2	†6.5	†4.3	†3.0	3.2	7.1	4.5	3
18	2.5	9.4	4.0	3.0	†2.1	7.9	4.2	3.15	3.6	7.1	4.5	3
19	2.9	8.5	4.1	3.0	1.9	8.2	4.3	3.1	4.1	†5.9	†4.3	†3
20	3.0	6.6	3.9	3.0	3.3	8.3	4.4	3.2	3.2	7.3	4.5	.
21	2.2	7.8	4.0	3.5	3.8	9.3	4.3	3.1	3.4	9.0	4.6	3
22	1.8	7.5	4.2	3.0	3.4	9.0	4.4	3.25	3.0	9.7	4.6	.
23	2.5	9.0	4.0	3.05	3.6	9.6	4.4	3.2	3.8	7.3	4.6	3
24	3.2	9.0	3.9	3.05	3.3	9.2	4.8	3.25	4.1	8.7	4.6	3
25	2.6	9.5	4.0	3.05	3.7	10.5	4.5	3.25	4.3	8.0	4.8	3
26	4.5	...	...	3.05	3.9	9.0	4.5	3.4	4.8	8.8	4.5	3
27	2.5	9.0	3.9	3.10	3.0	9.8	...	...	3.7	8.4	4.7	3
28	3.1	9.1	NR	NR	3.3	8.5	4.5	3.5	5.6	†7.0	†4.5	†3
29	2.1	9.6	4.4	3.10					†3.4	†7.2	†4.4	†3
30	3.3	9.8	4.2	3.2					†3.7	†6.9	†4.3	†3
31	3.4	8.4	4.2	3.1					†<1.7	†<3.9	†3.9	†3

† = Ionosphere-storm day. NR = No record.

National Bureau of Standards,
United States Department of Commerce,
Washington, D. C.

AMERICAN *URSI* BROADCASTS OF COSMIC DATA, GIVING AMERICAN MAGNETIC CHARACTER-FIGURE, C_A, THREE-HOUR-RANGE INDICES, K, AND MEAN K-INDICES, K_A, FOR JANUARY TO MARCH, 1941

Summaries of American *URSI* broadcasts have appeared regularly in this Journal since the issue for December 1930.

As set forth in this Journal for June, 1937, "The Department of Terrestrial Magnetism and the United States Coast and Geodetic Survey with the cooperation of the United States Army and the United States Navy communication-services and several amateur radio stations have

undertaken to supply the American character-figure based upon the reports of the seven American-operated observatories—those of the Department of Terrestrial Magnetism at Huancayo in Peru and at Watheroo in Western Australia, and those of the United States Coast and Geodetic Survey at Cheltenham (Maryland), Honolulu (Hawaii), San Juan (Puerto Rico), Sitka (Alaska), and Tucson (Arizona)." This character-figure is being designated C_A, and its values for the first twelve, the second twelve, and all twenty-four hours of each Greenwich day for January to March, 1941, are given in Table 1.

TABLE 1—*American magnetic character-figure C_A for Greenwich half-days based on reports from Cheltenham, Honolulu, Huancayo, San Juan, Sitka, Tucson, and Watheroo for January to March, 1941*

Day	January			February			March		
	0^h-12^h	12^h-24^h	0^h-24^h	0^h-12^h	12^h-24^h	0^h-24^h	0^h-12^h	12^h-24^h	0^h-24^h
1	0.2	0.7	0.5	0.0	0.1	0.0	2.0	2.0	2.0
2	0.1	0.2	0.1	0.0	0.3	0.1	1.1	0.9	1.0
3	0.0	0.2	0.1	0.7	0.5	0.6	0.7	1.0	0.9
4	0.2	0.0	0.1	0.3	0.3	0.3	1.0	0.9	1.0
5	0.0	0.5	0.2	0.4	0.8	0.6	0.7	0.9	0.8
6	1.1	0.4	0.8	0.8	0.6	0.7	0.7	0.5	0.6
7	0.2	0.4	0.3	0.9	0.7	0.8	0.4	0.5	0.4
8	0.2	0.2	0.2	0.5	0.4	0.4	0.6	0.4	0.5
9	0.4	0.5	0.5	0.4	0.4	0.4	0.5	0.1	0.3
10	0.2	0.3	0.2	0.3	0.1	0.2	0.4	0.1	0.2
11	0.0	0.3	0.1	0.0	0.1	0.1	0.1	0.5	0.3
12	0.0	0.2	0.1	0.0	0.1	0.0	0.1	0.5	0.3
13	0.0	0.1	0.1	0.7	1.1	0.9	0.4	0.6	0.5
14	0.0	0.1	0.0	0.7	0.4	0.6	1.4	1.0	1.2
15	0.1	0.1	0.1	0.9	0.5	0.7	0.6	0.5	0.6
16	0.1	0.6	0.3	0.1	0.4	0.2	0.0	0.0	0.0
17	1.0	1.3	1.1	0.6	0.6	0.6	0.0	0.0	0.0
18	0.7	0.9	0.8	0.1	0.1	0.1	0.0	0.1	0.1
19	0.4	0.6	0.5	0.1	0.4	0.2	0.2	0.9	0.6
20	0.4	0.4	0.4	0.2	0.6	0.4	0.8	0.9	0.8
21	0.4	0.0	0.2	0.5	1.1	0.8	0.8	0.8	0.8
22	0.0	0.1	0.1	0.7	0.9	0.8	1.0	0.7	0.9
23	0.4	0.9	0.6	0.6	1.0	0.8	0.4	0.8	0.6
24	0.8	1.0	0.9	0.6	0.6	0.6	0.3	0.2	0.2
25	0.8	0.6	0.7	0.3	0.6	0.4	0.3	0.1	0.2
26	0.4	0.5	0.5	0.4	0.3	0.4	0.0	0.0	0.0
27	0.4	0.6	0.5	0.1	0.1	0.1	0.0	0.0	0.0
28	0.4	0.4	0.4	0.2	0.1	0.2	1.1	1.4	1.2
29	0.0	0.1	0.0				0.9	1.1	1.0
30	0.2	0.4	0.3				1.1	1.7	1.4
31	0.0	0.0	0.0				1.6	0.8	1.2
Means	0.3	0.4	0.3	0.4	0.5	0.4	0.6	0.6	0.6

Since April 6, 1940, American *URSI* broadcasts have given three-hour-range indices, K, for each of the seven American-operated observatories. The eight indices for each day give geomagnetic activity for three-hour periods successively during the Greenwich day. The indices range

Table 2--Three-hour-range indices, K, January to March 1941

January 1941

	1	2	3	4	5	6	7	8
Si	0320 3432	1001 1110	0011 1011	2324 1110	0012 0210	2553 1131	1133 1431	1133 1112
Ch	1320 2334	2211 2221	1110 1223	2322 0110	0011 1222	4442 1232	2122 0232	2321 1123
Tu	1331 2233	2221 2211	1010 1023	2222 1101	0011 1222	3543 1232	1232 1332	1221 1222
SJ	1322 2333	1211 1241	0111 2333	2221 0221	0012 0322	5553 0231	2221 0322	2112 0112
Ho	1221 2332	1221 1011	1110 2012	3321 0000	0101 0222	5543 1133	3221 1334	1231 0133
Hu	1222 3433	2112 3312	1111 3321	2221 2221	0012 1432	4543 2443	2222 2432	2111 2232
Wa	1221 3433	2222 3211	1121 2122	2322 1211	0013 1322	4454 1222	1131 1532	1232 1122
	9	10	11	12	13	14	15	16
Si	1133 4221	1120 3211	1003 4111	0132 3110	1022 1011	1010 0000	0111 3100	0114 3411
Ch	2343 3332	2121 2222	3223 2122	2221 1121	3012 0022	1121 1012	2322 1120	1122 3322
Tu	1233 3321	2111 3321	2222 2122	1232 2121	3011 0112	1010 0021	0222 2110	2123 2212
SJ	1133 2230	2021 1232	2112 2032	1111 2122	2011 0122	0100 0123	0121 1121	2111 1123
Ho	2223 3222	2110 3111	2211 3111	1121 3021	1001 0022	1010 0021	0122 2021	1122 2213
Hu	1133 5543	2112 3442	2212 4343	2211 3443	2111 2453	1111 2232	0122 3221	2211 3532
Wa	2332 4231	3222 3321	2223 3232	2221 2322	1111 1122	2111 1021	1122 2111	2212 3423
	17	18	19	20	21	22	23	24
Si	4143 7633	3445 3343	2344 4322	3233 3122	1200 0111	0021 1121	1234 4642	1456 8643
Ch	5243 4535	5543 3355	5333 4334	4332 2133	3300 0111	1232 1132	3244 3344	4444 5533
Tu	6332 3533	4554 2255	4443 3323	3333 2123	3310 0001	0121 0221	2244 3332	3444 4443
SJ	5343 4545	3322 1454	3322 2332	3222 1233	3301 1111	1021 0133	2133 2342	2333 3532
Ho	5354 3444	3343 1133	4333 2122	2222 1023	3321 1101	0121 0121	2133 3333	3343 3433
Hu	5232 6754	3322 2553	1312 3432	3212 2243	3312 3211	1222 3441	2123 4542	2223 5542
Wa	5344 5634	3323 2443	2233 4432	3222 2123	2311 1101	1122 1121	2122 4453	3343 6532
	25	26	27	28	29	30	31	
Si	1355 4322	3244 4222	1154 4321	2104 3121	1122 0011	1222 3221	0031 0010	
Ch	3434 3334	5343 3233	2244 3333	4213 3232	3112 1212	2422 2232	2141 1010	
Tu	2435 3324	5343 2223	1243 3322	4213 2221	2112 1112	2321 2232	2131 1111	
SJ	2323 2434	4332 1232	0133 1222	3101 1230	2001 0223	2211 2231	2121 1012	
Ho	2334 3322	3223 2111	1123 3222	2213 3020	1013 1002	3321 3011	1121 1010	
Hu	2312 5442	3223 3432	1132 4542	3112 4333	1112 3322	2212 3431	1121 2231	
Wa	2334 3422	3334 3322	1223 4333	1223 3222	2112 1213	2222 4242	1121 2111	

February 1941

	1	2	3	4	5	6	7	8
Si	0012 3210	0022 1021	2466 4432	1223 3121	1122 3333	3355 4231	2445 3322	1355 4221
Ch	0121 2222	1122 2123	3444 2233	3222 3121	3322 3234	5444 3333	4542 3333	3434 3332
Tu	1222 2331	1022 1022	3444 3233	2222 2311	3222 3334	4444 3222	3543 3333	3435 3322
SJ	1111 2110	0021 1232	3433 1232	3221 1111	2221 1343	3333 1232	4432 2333	3323 0331
Ho	1111 2021	1122 0140	2434 2232	1122 1111	1123 3223	3233 3222	1534 2121	3334 3210
Hu	1111 3331	1022 3331	2322 3432	2211 5442	2222 4553	3323 4432	3322 4442	2212 4332
Wa	1212 3231	2123 2132	3344 3232	2222 2212	3122 3334	3443 3233	3434 4333	3323 2342
	9	10	11	12	13	14	15	16
Si	2351 2122	2231 3110	1122 1010	0014 1000	1155 7442	3346 3321	2534 4222	1112 1123
Ch	3431 1233	4232 1122	2120 1122	1112 2021	3344 5433	5444 3222	4534 4343	4412 1234
Tu	2431 1321	2231 2212	2220 0111	1212 1111	3244 3433	4344 2322	3534 3331	3312 1114
SJ	2321 0142	3221 0111	1120 0011	1100 0111	2333 4333	4333 1311	4423 3231	3300 0114
Ho	1331 1121	1221 3110	1120 1010	0102 1002	2353 5323	3334 2211	2423 3221	3111 2124
Hu	2311 3442	2221 2432	1111 2433	1111 3332	2243 5553	3323 4422	3323 4542	2111 2333
Wa	3221 3222	2222 3112	1111 2131	2112 1121	2244 4533	3235 3322	4323 3332	3322 1233
	17	18	19	20	21	22	23	24
Si	2456 4232	1023 3121	0012 1211	0033 4232	3213 6644	2435 6543	2254 6554	2355 4522
Ch	3543 3232	1223 2121	1112 2321	1134 3244	6312 5455	4534 3554	4453 3455	4444 3434
Tu	3444 3222	2123 3122	1112 1221	1232 2233	4313 4435	4535 3543	3344 3454	2343 3432
SJ	2333 2222	1212 0121	0111 1211	1222 2233	4201 4345	2423 2443	4332 4344	2333 2422
Ho	1224 2111	0113 2011	0111 1111	1122 2233	3303 4342	2334 3333	2243 3333	2233 2221
Hu	2223 5432	2212 2331	1111 2443	2222 3443	3312 5553	2323 5653	3331 4543	2212 3432
Wa	2235 4232	2122 2121	2121 1312	2112 3223	3213 5545	2324 4432	3232 4454	3323 4433
	25	26	27	28				
Si	1245 5232	3324 3220	0001 1111	1225 3010				
Ch	3334 3343	4334 2331	1111 1321	2213 2321				
Tu	2233 3343	4323 2221	0012 1212	3214 2302				
SJ	3122 3232	3311 0220	0000 0320	2212 0110				
Ho	1213 3222	3124 1130	0011 0001	1214 0001				
Hu	2121 4532	3312 2341	1112 1521	2223 2421				
Wa	3333 4232	3323 3321	2222 2221	3323 2211				

Table 2--Three-hour-range indices, K, January to March 1941--concluded

March 1941

	1	2	3	4	5	6	7	8
Si	3689 9976	4466 3533	3335 6532	4455 5523	3634 7434	3444 2332	2123 1232	3322 2111
Ch	3689 9976	5434 3434	4334 4433	5445 4434	4633 4334	4344 3332	3222 1244	4312 2223
Tu	2688 9976	3444 2433	4324 3432	5444 4434	4542 4333	4444 3333	3223 1234	4322 2213
SJ	3676 9654	6323 2423	3323 3332	4333 3334	3421 4333	3223 0331	2212 1234	3211 2012
Ho	2597 8755	4444 2222	2324 3332	4443 3324	3333 3222	2334 2112	2223 2133	2322 2132
Hu	3576 9985	3223 3343	2322 3542	3333 5534	2423 4333	3332 3421	3223 2353	3221 3322
Wa	3687 8995	3245 2344	3224 4332	3334 4534	3322 6444	3333 2332	2223 1333	3221 2333
	9	10	11	12	13	14	15	16
Si	3252 1122	2422 2110	1212 2133	1001 4222	2220 0234	6678 8434	2344 4322	2122 2110
Ch	5332 1234	3422 1131	3211 2135	2211 3323	3321 0344	5666 4445	3444 3244	3322 2120
Tu	4242 1234	4422 2121	2112 2135	2211 3323	3321 1334	5655 5335	1333 3223	2322 1121
SJ	4120 3123	2310 0021	2101 1225	2102 1433	2220 1144	5455 4334	2333 3222	3201 1120
Ho	2232 1133	3222 1111	1211 2224	2112 3213	2211 0223	6554 4234	2233 3222	2212 0110
Hu	3221 2321	2310 2321	2210 2333	2112 4443	2211 2443	4444 4443	2222 3432	2101 2231
Wa	3232 1233	2211 1331	2111 2224	2211 3233	3321 1233	5455 6444	2214 3233	2112 2112
	17	18	19	20	21	22	23	24
Si	0021 2110	1011 1112	0126 6432	2366 5533	2445 5343	4546 6332	1133 3333	1023 1221
Ch	2321 2122	3221 1124	1224 5443	6344 3444	4454 3444	5534 3444	3343 3444	3322 2333
Tu	1221 1211	2221 0113	2224 5434	4444 3434	4454 3353	5534 4433	2333 1325	2222 2333
SJ	0111 1000	1110 0124	1223 4333	4232 2423	3433 3033	4433 2323	1221 2323	2220 1223
Ho	0021 2001	1120 0123	1243 4332	2334 3323	3334 2142	3433 3223	3233 2324	2213 1111
Hu	1102 3221	1221 2323	1234 5642	3232 4443	3332 4543	3432 3442	1211 3543	1211 2321
Wa	1011 2110	1011 0113	1112 5433	2234 4333	2234 3342	3334 5433	2223 2434	2122 2322
	25	26	27	28	29	30	31	
Si	0234 1121	1233 0010	0001 1002	2227 7643	4344 5444	3556 6866	5668 6321	
Ch	1223 2122	2331 0120	0001 1012	4435 5555	5443 3355	5543 3667	6656 5333	
Tu	0323 1221	1331 0111	0000 0111	5535 4555	4442 3344	5553 2654	6656 4332	
SJ	0212 0021	1221 0001	0010 0021	5433 4554	4323 2354	4334 3565	5535 4332	
Ho	0123 2011	1211 0011	0001 1012	4335 4552	4343 3233	4444 3465	5655 4333	
Hu	0212 3331	1210 1120	1010 2221	5334 5664	4212 4544	3333 4656	5424 4532	
Wa	2122 1122	2111 1111	1111 2111	4335 6554	4323 4444	3345 4656	5446 4342	

Table 3--Weighted average of reduced three-hour-range indices, January to March 1941

Day	January 1941 Values K_A	Sum	February 1941 Values K_A	Sum	March 1941 Values K_A	Sum
1	1 3 2^x 1 2 3 3 3	18^x	0^x 1^x 1^x 1^x 2 2 2 1	12	3 5^x 8 8 8^x 8^x 7 5^x	54
2	2 2 1^x 1^x 2 1^x 1^x 1	13	1 0^x 2 2 1^x 1 2^x 2	12^x	4 3 3^x 4 2^x 3^x 3 3^x	27
3	1 1 1^x 0^x 1^x 1 2 2^x	11	3 4 4 4 2^x 2^x 3 2^x	25^x	3 3 2^x 4 3^x 4 3 2	25
4	2^x 3 2 2 0^x 1^x 1 0^x	13	2^x 2^x 2 2 2^x 2 1^x 1^x	16^x	4 3^x 3^x 4 4 4^x 2^x 4	30
5	0 0 1 2 0^x 2^x 2 1^x	9^x	2^x 2 2 2 2^x 3 3 3^x	20^x	3^x 4^x 2^x 2^x 4^x 3^x 3 3^x	27^x
6	4 5 4^x 3 1 2 3 2	24^x	4 3^x 4 3^x 2^x 2^x 3 2^x	25^x	3^x 3 3 3^x 2^x 3 2^x 2	23
7	2 2 2^x 1^x 1 3^x 3 2	17^x	3^x 4^x 3^x 3^x 3 2^x 3 2^x	26	2^x 2 2 2^x 1^x 2^x 3^x 3^x	20
8	2 2 2^x 1^x 1 1^x 2 2^x	15	3 3^x 3 3^x 2^x 2^x 2^x 1^x	22	3^x 2^x 2 1^x 2^x 2 2 2^x	18^x
9	2 2^x 3 2^x 3^x 2^x 3 1^x	20^x	3 3^x 3 1 1^x 2 2^x 2	18^x	3^x 2 3 1^x 1^x 2 2^x 3	19
10	2^x 1^x 2 1 2 2^x 2 1^x	15	3 2^x 2^x 1^x 2 1^x 1^x 1^x	16	2^x 3 1^x 1^x 1^x 1^x 2 0^x	14
11	2^x 1^x 1^x 2^x 2^x 1^x 2 2	16	1^x 1^x 2 0^x 1 1 2 1	10^x	2 2 1 1^x 2 2 2^x 4^x	17^x
12	1^x 2 2 1 2 1^x 2 1^x	13^x	1 1 1 2 1^x 0^x 1 1	9	2 1^x 1 1^x 3 3 2^x 3	17^x
13	2 0^x 1 1^x 0^x 0^x 2 2	10	2^x 2^x 4 4 4^x 4 3^x 3	28	2^x 2^x 2 1 0^x 2^x 3^x 4	18^x
14	1^x 0^x 1 0^x 0^x 0 1^x 1^x	7	4 3 3^x 4^x 2^x 2^x 2 2	24	5^x 5 5 5^x 5 4 3^x 4^x	38
15	0^x 1^x 2 2 2 1 1^x 0^x	11	3^x 4^x 2^x 3^x 3 2^x 3 2	24^x	2 3 3 3^x 3 2^x 2^x 3	22^x
16	1^x 1^x 1^x 2 2 3 1^x 2^x	15^x	3 3 1 1^x 1 2 2^x 4	18	2^x 2 1^x 2 2 1^x 1^x 0^x	13^x
17	5^x 3 4 3 4^x 5 3^x 4^x	33	2^x 3^x 3^x 4 3 2 2^x 2	23	0^x 1 1^x 1^x 2 1 1 0^x	9
18	4 4 3^x 3 2 3 4^x 4	28	1^x 1^x 2 2^x 2 1 2 1^x	14	1^x 1 1^x 1 0^x 1^x 1^x 3^x	12
19	3^x 3 3 3 3 3 2^x 2^x	23^x	1 1 1^x 1^x 1^x 2^x 1^x 1^x	12	1 2 2^x 3^x 4^x 4 3^x 3	24
20	3^x 2^x 2^x 2 2 1 2^x 3	19	1^x 1^x 2^x 2^x 2^x 2^x 3 3	19	3^x 2^x 3^x 4 3^x 4 3 3^x	27^x
21	3 3 0^x 0^x 0^x 1 0^x 1	10	4^x 3 1 2^x 4^x 4 4^x 4^x	28^x	3 3^x 3^x 4 3^x 3 4 3	27^x
22	0^x 1 2^x 1^x 1 1^x 2^x 1^x	12	3 4 2^x 4 3^x 4 4 3	28	4 4 3 3^x 3^x 3^x 3 3	27^x
23	2^x 1^x 3 3 3^x 3^x 4 3	24	3^x 3 4 2^x 3^x 3^x 4^x 4	28^x	2 2 2^x 2^x 2^x 4 3 4	22^x
24	3 3^x 4 3^x 5 4^x 3^x 2^x	29^x	3 3 3 3^x 3 3^x 2^x 2^x	24	2 1^x 2 2 2 2^x 2 2	16
25	2^x 3^x 3 4 3 3 2^x 3	24^x	2^x 2^x 3 3 3^x 2^x 3 2^x	22^x	0^x 2 2 2^x 1^x 1 2 1^x	13
26	4 3 3^x 3^x 2^x 2^x 2^x 2^x	24	3^x 3 2 3 2 2^x 2^x 0^x	19	1^x 2 2 1^x 0^x 0^x 1 0^x	9^x
27	1^x 2 3^x 3 3 3 2^x 2^x	21	1 1 1 1^x 1 2 1^x 1	10	0^x 0 0^x 1 1 0^x 1 1^x	6
28	3 2 1 3 2^x 2 2^x 1^x	17^x	2^x 2^x 1^x 3^x 1^x 1^x 1 1	15	4 3^x 3 5 5 5^x 5 4	35
29	2^x 1 1 2 1 1^x 1 2^x	12^x			4^x 3 3 3 3^x 3^x 4^x 4^x	29^x
30	2^x 3 2 1^x 2^x 2 3 1^x	18			4 4 4 4 3^x 6 5^x 6	37
31	1^x 1 3 1 1 0^x 1 0^x	9^x			5^x 5 4 6 4 3^x 3 2	33

from "zero" very quiet to "nine" extremely disturbed. The K-indices for Sitka (Si), Cheltenham (Ch), Tucson (Tu), San Juan (SJ), Honolulu (Ho), Huancayo (Hu), and Watheroo (Wa), for January to March 1941, are given in Table 2. Interpolated indices are shown thus: $\ddot{3}$.

In the manner set forth in the Journal for September, 1940, the indices are standardized into reduced indices K_r to eliminate local variations. A weighted mean index, K_A, is derived from the reduced indices. The reduced indices from Si, Ch, and Wa, are given double weight and those from Tu, SJ, Ho, and Hu, are given single weight. The weighted indices, K_A, for January to March, 1941, are given in Table 3. A superior cross (×) following an index-number denotes a half-unit, thus $5^{\times}=5.5$, etc.

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Washington, D. C., April 25, 1941

SOLAR AND MAGNETIC DATA, JANUARY TO MARCH, 1941, MOUNT WILSON OBSERVATORY

A great magnetic storm, the most intense since that of March 24, 1940, began suddenly on March 1 at $03^h\ 58^m$ GMT. A complex sunspot-group, Mount Wilson No. 8032, which crossed the central meridian on February 27.3 in latitude +16° was then 24° west. This spot-group consisted of one penumbral area surrounding four or five umbrae, the preceding having S polarity, the following, N polarity. This is contrary to the usual order of polarities in bipolar groups of the present sunspot-cycle. This group was much like that associated with the great storm of March, 1940, but had less than half the area.

Magnetic storms

Greenwich mean time						Range hor. int.
Beginning			Ending			
1941	*h*	*m*	*d*	*h*	*m*	γ
Mar 1	03	58*	6	23	..	>630
28	01	..	31	22	..	200

*Sudden commencement

The present storm began with a sudden increase of 60 gammas in H, which fluctuated for two hours and then decreased. The total range in H was more than 639 gammas. The greatest activity occurred between 14^h and 18^h GMT, March 1. Except for a few very short intervals, the H-curve was off the record from 16^h to 18^h. The last phase of the storm, when the field-strength was returning to normal, was very prolonged. Seven days after the period of maximum activity, the horizontal-field strength, although slowly increasing, was still below normal. Although the range in H was large, at no time were the fluctuations as rapid as those of the great storm of 1940.

Day	January 1941 K₂ Whole disk	K₂ Central zone	H_α bright	H_α dark	No. groups	Mag'c char.
1	2	1	2[c]	2	7	0
2	3	2	3	1	7	0
3	3	3	3	2	7	0
4	..	..	..	..	..	0
5	..	..	..	..	..	0.5
6	..	..	..	..	..	1
7	..	..	..	..	..	0
8	..	..	..	..	7	0
9	..	..	..	..	..	0.5
10	..	..	..	..	..	0
11	2	2	2	1	7	0
12	2	3	3	1	7	0
13	2	2	2	2	3	0
14	2	2	3	1	3	0
15	2	2	3	1	4	0
16	3	2	3	1	3	0.5
17	2	2	3	1	3	1
18	2	2	2	1	4[b]	0.5
19	2	2	2	1	2	0.5
20	..	..	..	..	2	0.5
21	..	..	..	..	..[e]	0.5
22	2	3	2	2	3	0
23	..	..	..	..	..	0.5
24	..	..	..	..	..	1
25	..	..	..	..	5	0.5
26	..	..	..	..	..	0.5
27	2	1	3	4	5	0.5
28	..	..	..	..	..	0.5
29	..	..	..	..	6	0
30	3	4	4	3	6	0
31	3	3	3	2	6[h]	0
Mean	2.3	2.2	2.7	1.6	4.8	0.3

Day	February 1941 K₂ Whole disk	K₂ Central zone	H_α bright	H_α dark	No. groups	Mag'c char.
1	..	..	..	..	7	0
2	3	3	3	2	6	0
3	3	3	3	2	7	0.5
4	3	2	3	2	10[f]	0.5
5	3	3	3	1	12	0.5
6	..	..	..	..	6	0.5
7	3	2	3	1	5	1
8	..	..	..	..	..	0.5
9	2	2	2	1	5	0.5
10	2	2	2	2	5	0
11	..	..	..	..	..	0
12	..	..	..	..	2	0
13	2	2	2	2	4	1
14	..	..	..	..	3	0.5
15	..	..	..	..	..	1
16	..	..	..	..	..	0.5
17	..	..	..	..	..	0.5
18	2	1	..	..	2	0
19	..	..	..	..	..	0
20	..	..	..	..	..	0.5
21	..	..	..	..	..	1
22	..	..	..	..	..	1
23	..	..	..	..	3	1
24	..	..	..	..	..	1
25	..	..	..	..	5	0.5
26	2	3	3	1	5	0.5
27	3	3	3[c]	1	6[i]	0
28	..	..	..	..	..	0
29						
30						
31						
Mean	2.5	2.4	2.7	1.5	5.5	0.5

Day	March 1941 K₂ Whole disk	K₂ Central zone	H_α bright	H_α dark	No. groups	Mag'c char.
1	..	..	..	..	..	2
2	..	..	..	..	..	1
3	..	..	..	..	..	1
4	..	..	..	..	..	1
5	..	..	..	..	4	...
6	2	2	2	2	6[a]	1
7	2	2	2	1	5	0.5
8	1	2	2	2	3	0.5
9	1	1	2	1	3	0.5
10	2	1	2	1	3	0
11	..	..	..	..	4	0.5
12	..	..	..	..	..	0.5
13	..	..	..	..	..	0.5
14	..	..	..	..	..	...
15	2	2	3	2	5	0.5
16	2	1	2	2	7	0
17	2	2	3	2	7	0
18	2	2	3	2	5	0
19	2	2	3	2	6[h]	0.5
20	2	3	3	2	5	0.5
21	3	2	3	2	5	1
22	3	2	2	2	7	1
23	3	2	3	2	5	0.5
24	2	2	2	2	5	0
25	2	1	2	2	6	0
26	2	1	2	2	5	0
27	2	2	2	2	7	0
28	..	..	..	..	..	1.5
29	..	..	..	..	..	1
30	..	..	..	..	3	1.5
31	..	..	..	..	..	1.5
Mean	2.1	1.8	2.4	1.8	5.0	0.6

NOTE—For an explanation of these tables see this JOURNAL, **35**, 47-49 (1930).

The character-figures of solar phenomena are estimated from the spectroheliograms which are made with a 2-inch solar image, usually in the early morning. Very bright chromospheric eruptions are reported in these notes if observed at any time during the day.

[a], [b] Formation of a new group which later developed to average size or larger; (*a*) less than 30° from the center of the disk, (*b*) more than 30° from the center of the disk.

[c], [d] Very bright chromospheric eruptions; (*c*) less than 30° from the center of the disk, (*d*) more than 30° from the center of the disk.

[e], [f], [g], [h], [i], [j], [k], [l] Passage of a large or active group across the central meridian within 5°, 10°, 15°, 20°, 25°, 30°, 35°, 40° of the center of the disk, respectively.

The storm of March 28 followed the great storm of March 1 by about half a day less than a solar rotation. Group No. 8032 did not return and the spectroheliograms showed no evidence of activity in the region where it had been. The largest group on the Sun at the beginning of the storm of March 28 was No. 8056, 13° east of the central meridian. This group was a return of No. 8034, which was 9° east when the storm of March 1 began.

Seth B. Nicholson
Elizabeth Sternberg Mulders

Carnegie Institution of Washington,
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Pasadena, California

NOTES

(See also page 238)

11. *Hong Kong Observatory*—Dr. C. W. Jeffries, Director, Royal Observatory of Hong Kong, informs us that magnetic registrations, which were suspended on June 17, 1940, were resumed on January 1, 1941, at the Au Tau Magnetic Observatory.

12. *First award of the Charles Chree Medal and Prize*—The Council of the Physical Society of London has made the first award of the Charles Chree Medal and Prize to Professor *S. Chapman*, of the Imperial College of Science and Technology "in recognition of his work in terrestrial magnetism." This medal and prize were founded by Miss Chree in memory of her brother.

13. *Ionospheric and magnetic station at College, Alaska*—The Department of Terrestrial Magnetism has arranged for the installation, by L. V. Berkner of its staff, with the assistance of Dr. E. H. Bramhall, professor of physics, of a multifrequency recording ionospheric equipment on the campus of the University of Alaska, as well as of a magnetic recording station. A program of auroral observations for correlative studies will also be carried out. S. L. Seaton, also of the Department's staff, will assist Mr. Berkner in the installation.

14. *Transit-magnetometer*—Three more transit-magnetometers are being equipped by the United States Coast and Geodetic Survey with deflector and deflector-attachments for use in determination of horizontal intensity. Experience with these instruments in the field has indicated that they will give results which are of the same order of accuracy as those obtained with an ordinary field-magnetometer. The intensity-attachments are of rugged construction and are so designed that observations can be made with considerable speed.

15. *Corrigenda*—In the March 1941 number of the Journal the running-heads on pages 80 and 82 should be interchanged with those on pages 84 and 86 and the running-head on page 81 should be interchanged with that on page 85.

16. *Personalia*—On March 31, 1941, *George Hartnell* retired from the United States Coast and Geodetic Survey after 33 years of service. At the Cheltenham Magnetic Observatory, where for many years he conducted important theoretical research on problems relating to the meas-

urement of the Earth's magnetism, some 75 friends gathered for the ceremonies. Captain *N. H. Heck* and Captain *P. C. Whitney* of the United States Coast and Geodetic Survey and Dr. *J. A. Fleming*, Director, Department of Terrestrial Magnetism, Carnegie Institution of Washington, made brief and appropriate remarks at the conclusion of which *A. K. Ludy* who presided over the ceremonies presented, on behalf of those present, an Underwood typewriter. In his reply, Mr. Hartnell spoke of his long service in the Survey, first at the Vieques Observatory in Puerto Rico, and of his field work in Cuba and Florida, and finally of the outstanding events in the history of scientific instruments and measurements during his many years at Cheltenham. Mr. and Mrs. Hartnell plan to return to their old home in Wyoming, New York, where he will complete several scientific papers on which he is working.

The following changes have been made in personnel at the magnetic observatories of the United States Coast and Geodetic Survey: Lieutenant *B. H. Rigg* relieved Lieutenant *E. O. Heaton* as observer-in-charge at Honolulu, Territory of Hawaii, March 4, 1941; *J. H. Nelson* relieved *R. F. White* as observer-in-charge at Tucson, Arizona, April 15, 1941.

We regret to record the death on January 29, 1941, of *Daniel M. Wise*, staff-supervisor, Plane Engineering Department, American Telephone and Telegraph Company, Philadelphia, Pennsylvania, aged 53 years. From April 15, 1913, until November 30, 1919, Mr. Wise was employed as a magnetic observer by the Department of Terrestrial Magnetism of the Carnegie Institution of Washington. During this period he carried out magnetic field-work in Canada, Africa, and South America, and took part in solar-eclipse expeditions to Lakin, Kansas (June 8, 1918) and to Sobral, Brazil (May 29, 1919), being in charge of the latter expedition.

We have learned with regret of the death on July 6, 1940, of *Jules-M. Ch. Jaumotte*, Director of the Royal Institute of Belgium, aged 53 years. Aside from his important meteorological researches, he took an active part in international scientific organizations having been a member of the Belgian National Committee of Geodesy and Geophysics (1921), the Belgian Commission of the Polar Year 1932-33, and the Commission appointed for establishing a liaison between the International Meteorological Organization and the International Scientific Radio Union (1938).

We regret to record the death on May 20, 1941, of Lieutenant-Commander *Ernest W. Eickelberg*, at the age of 51 years. During the period 1931-1938, he was Assistant Chief of the Division of Terrestrial Magnetism and Seismology of the United States Coast and Geodetic Survey. Thereafter up to the time of his last illness he had been commanding officer of the *Explorer* and the *Guide*, Coast and Geodetic Survey vessels on service in Alaska.

PRINCIPAL MAGNETIC STORMS

SITKA MAGNETIC OBSERVATORY

JANUARY TO MARCH, 1941

(Latitude 57° 03′.0 N., longitude 135° 20′.1 or $9^h 01^m.3$ W. of Gr.)

January 17-19—A sudden commencement was recorded at $00^h 10^m$ GMT, January 17; the disturbance gradually increased but was not very great at any time. By the close of January 19 the conditions were normal. Ranges: *D*, 40′; *H*, 552 gammas; *Z*, 405 gammas.

January 23-25—A moderately disturbed period began gradually at about 08^h GMT, January 23, with the disturbance increasing gradually in intensity until about 13^h, January 24. It then began to subside. The magnetic elements were normal at the close of January 25.

March 1-2—A severe storm began abruptly at $03^h 59^m$ GMT, March 1. The intensity of the storm increased rapidly with a particularly large movement of 148′ in declination at $09^h 42^m$. From 13^h to 18^h the record is nearly unreadable because of the large rapid swings of the three elements. As near as can be determined about five hours of the *Z*-record were lost by the trace being off the paper. The turning points of the maximum and minimum values in *D*, *H*, and *Z* are highly uncertain. By 24^h, March 2, the values were about normal. The trace however remained quite disturbed until March 6.

March 14-15—A small magnetic storm began abruptly at about 01^h GMT, March 14, with rapidly increasing intensity and reached maximum values at 12^h. Thereafter the trace returned to normal values. It was very quiet at the close of March 15. Ranges: *D*, 162′; *H*, 1240 gammas; *Z*, 1144 gammas.

March 28-30—An extended period of storminess began abruptly at 09^h GMT, March 28. The conditions remained badly disturbed with large bays until the storm ended March 31.

March 30-31—A small storm began suddenly at $16^h 38^m$ GMT, March 30, with a sudden movement of all elements. The storm consisted of large bays with superimposed short-period motion. After $12^h 30^m$, March 31, the storm gradually subsided. The trace was calm by 21^h, March 31. Ranges *D*, 110′; *H*, 1165 gammas; *Z*, 1030 gammas.

ROBERT E. GEBHARDT, *Observer-in-Charge*

CHELTENHAM MAGNETIC OBSERVATORY

JANUARY TO MARCH, 1941

(Latitude 38° 44′.0 N., longitude 76° 50′.5 or $5^h 07^m.4$ W. of Gr.)

January 16-21—On January 16 at $20^h 30^m$ GMT, a disturbance of mild proportions began and continued until the end of January 21. The greatest *K*-number during this interval was 5 which occurred eight times in the five days.

January 23 28—The field again became disturbed on January 23

and continued so until January 28. During this time there were three K-numbers as great as 5.

February 2-9—A period of moderate disturbance lasting more than a week began February 2 about 17^h GMT. The perturbations were irregular and the highest K-number was 5.

February 13-16—A disturbance began at $00^h\ 35^m$ GMT, February 13, and ended February 16 at 23^h. The greatest K-number for this interval was 5.

February 20-26—A storm began gradually at 08^h GMT, February 20, and continued until February 26. The perturbations were irregular in period and amplitude. The highest K-number, 6, occurred in only one three-hour interval during the storm.

March 1-7—A great storm began March 1 at $03^h\ 57^m$ GMT. It was violent between 06^h and 21^h. There were three consecutive three-hour intervals when the K-numbers were 9. Ranges: D, 164′; H, 1367 gammas; Z, 761 gammas. The storminess, though not great, continued until 03^h, March 7.

March 13-17—A mild storm began at 15^h GMT, March 13, and from a slightly disturbed beginning gradually increased in violence until the main phase of the storm was reached at $00^h\ 38^m$, March 14. All three elements were moderately disturbed then until 15^h, March 14, when the storm gradually subsided and ended at 06^h, March 17. Ranges: D, 37′; H, 130 gammas; Z, 174 gammas. The greatest K-number was 6 which occurred for three consecutive three-hour intervals.

March 19-22—A disturbed period was registered between 11^h GMT, March 19, and 24^h, March 22. During this time the elements were active but the amplitudes were not large. The highest K-number was 6 which occurred but once.

March 28-31—A storm began March 28 at $00^h\ 30^m$ GMT, with a large, rather smooth bay in H covering four hours. The perturbations then became irregular. Before the end of this storm another began sharply at $16^h\ 36^m$, March 30. The second storm was more severe than the first. It ended at 24^h, March 31. Ranges for the first storm: D, 32′; H, 135 gammas; Z, 149 gammas; highest K-number 5. For the second storm: D, 46′; H, 264 gammas; Z, 420 gammas; highest K-number 7.

ALBERT K. LUDY, *Observer-in-Charge*

TUCSON MAGNETIC OBSERVATORY

JANUARY TO MARCH, 1941

(Latitude 32° 14′.8 N., longitude 110° 50′.1 or $7^h\ 23^m.3$ W. of Gr.)

March 1-3—A severe storm began at $03^h\ 57^m$ GMT, March 1, with an increase in H of 74 gammas in three minutes. The variations were large and rapid. At about 16^h the H-reserve spot went off scale negative for a range in H in excess of 550 gammas. The range in D was about 50′. The most active part of the storm ended at about $19^h\ 30^m$, March 1, and was followed by less intense activity for thirty-six hours. There was no definite ending to the lesser activity.

March 28-31—A moderate storm began at $04^h\ 30^m$ GMT, March 28, with minor variations in H, followed at about $09^h\ 00^m$ with small, rapid

changes in D. This storm continued with small variations until $16^h 36^m$, March 30, at which time there was a sudden increase in activity, especially in H. The storm ended abruptly at $13^h 00^m$, March 31, and was unusual in that the greatest activity was near the end rather than at the beginning of the storm.

Roland F. White, *Observer-in-Charge*

Huancayo Magnetic Observatory

December, 1940, to March, 1941

(Latitude 12° 02′.7 S., longitude 75° 20′.4 or $5^h 01^m.4$ W. of Gr.)

December 20-25—A moderate disturbance in H accompanied also by definite disturbances in D and Z began gradually about 13^h GMT, December 20, and was marked by a series of sharp peaks and bays lasting until about 20^h. The disturbance was followed by subnormal values and mild disturbances in H until December 25.

December 31—A sharp disturbance in H of short duration was recorded on December 31. It began at $13^h 25^m$ GMT, with a rapid rise followed by a rapid fall to a narrow bay, then about an hour later at $14^h 30^m$ a rise of 170 gammas occurred in ten minutes to reach a high peak followed by a fall of 300 gammas to a sharp bay in twenty minutes. The next three hours was a period of moderate disturbance, followed by several hours of subnormal values in H and with a return to practically normal conditions at 22^h. Both D and Z were somewhat disturbed from the beginning of the storm until after 17^h.

January 5-6—Beginning at $15^h 44^m$ GMT, January 5, there was a short fall and rapid rise in H not followed by any particular disturbance except for subnormal values in H during the hours from 02^h to 08^h, January 6.

January 16-17—At 15^h GMT, January 16, there was a deep fall in H followed by a mild disturbance that continued into the next day and was accompanied by several hours of subnormal values in H. Conditions had returned practically to normal by 24^h, January 17.

March 1-2—This short but very violent magnetic storm began abruptly at $03^h 57^m$ GMT, March 1, with an increase in H of 80 gammas in four minutes which was followed by about two hours of moderate disturbance. There was a deep bay at about 07^h which was followed by a moderate increase in H and then a second deeper bay which reached a minimum of 29230 gammas at $09^h 53^m$, this bay in turn being followed by another peak. At 12^h the peaks were succeeded by rapid fluctuations and a great increase in horizontal intensity, reaching the maximum, 29870 gammas at $13^h 18^m$. During the next three hours there were rapid fluctuations and a general decrease in horizontal intensity which reached a first minimum of 28710 gammas at $16^h 27^m$; this was followed by a rapid increase again to 29620 gammas at $17^h 04^m$ with a second peak of about the same height at $17^h 22^m$. In the next forty minutes the horizontal intensity decreased over 900 gammas, reaching the minimum of the storm, 28690 gammas, at $18^h 25^m$; then H increased to about 29100 gammas and remained at that level under moderately disturbed conditions until the violence of the storm stopped rather abruptly at about $23^h 30^m$. The following day was unusually quiet, horizontal intensity re-

maining low. There was a complete fade-out on the ionospheric record from about $11^h 49^m$ to $12^h 45^m$, March 1.

March 14-15—At 00^h GMT, March 14, there was a moderate decrease accompanied by a disturbance in horizontal intensity. Several small peaks and bays were recorded in the period up to 21^h. Abnormally low values of horizontal intensity were encountered up to 07^h, March 15.

March 19—Beginning at 11^h GMT, March 19, a sharp disturbance in H was recorded. There was a gradual decrease to a deep bay at 13^h, a small peak at 14^h, and a second bay at $14^h 40^m$. The trace then rose to practically normal position during the next hour.

March 28-30—Beginning at about 00^h GMT, March 28, there was a moderate disturbance marked by irregular movements and decrease in the value of H, followed by greater activity with several small peaks and bays during the period from 13^h to 21^h. The next two days were marked by abnormally low values of H and a very deep bay in H between 20^h and 24^h, March 30.

PAUL G. LEDIG, *Observer-in-Charge*

ALIBAG MAGNETIC OBSERVATORY[1]

OCTOBER TO DECEMBER, 1940

(*Latitude 18° 38′.3 N., longitude 72° 52′.3 or $4^h 51^m.5$ E. of Gr.*)

October 26—A moderate disturbance began suddenly at $07^h 23^m$ GMT, October 26. H attained its maximum at $08^h 02^m$ and then began to fall with fluctuations to reach the minimum at $17^h 20^m$. The disturbance ended at approximately $23^h.5$. Ranges: D, 4′.9; H, 185 gammas; Z, 45 gammas.

November 12-13—A moderate disturbance began with a sudden commencemt at $07^h 06^m$ GMT, November 12. H attained its maximum at $07^h 38^m$, and then fell until $11^h.5$, November 12, after which the oscillations became more pronounced. The minimum in H occurred at $05^h 01^m$, November 13. The disturbance practically ended at 08^h, November 13, although minor fluctuations continued for a period of short duration. Ranges: D, 3′.5; H, 145 gammas; Z, 117 gammas.

November 21—A moderate storm of short duration began gradually at about 05^h GMT, November 21. H reached its maximum at $06^h 09^m$ and then fell with moderate fluctuations. The minimum in H was attained at $11^h 06^m$. The storm ended at about 16^h. Ranges: D, 3′.6; H, 156 gammas; Z, 26 gammas.

November 25-26—A moderate disturbance commenced gradually at about 08^h GMT, November 25. The maximum in H occurred at the time of commencement of the disturbance and the minimum was attained at $14^h 44^m$, November 25. The disturbance ended at about 20^h, November 26. Ranges: D, 6′.7; H, 166 gammas; Z, 35 gammas.

December 30-31—A moderate disturbance began at $04^h 26^m$ GMT, December 30, with a sudden rise of 27 gammas in H. The maximum in H was recorded at $03^h 53^m$, December 31, and the minimum at $16^h 58^m$, December 31. The disturbance ended at 17^h, December 31. Ranges: D, 9′.2; H, 117 gammas; Z, 38 gammas.

DEPARTMENT OF TERRESTRIAL MAGNETISM, *Bombay Observatory, India*

M. R. RANGASWAMI

[1]Communicated by Dr. S. R. Savur, Director, Bombay and Alibag Observatories.

Watheroo Magnetic Observatory

January to March, 1941

(Latitude 30° 19′.1 S., longitude 115° 52′.6 or 7^h 43^m.5 E. of Gr.)

January 3-4—A small magnetic disturbance began with a sudden commencement at 15^h 43^m GMT, January 3. A quiet period of eleven hours ensued, after which the traces were mildly disturbed until normal conditions resumed at 12^h, January 4. Ranges: D, 14′.1; H, 85 gammas; Z, 59 gammas.

January 24—During somewhat disturbed conditions which prevailed on January 24, there was one noteworthy feature. Between 12^h and 14^h there was a wave of large amplitude in all three elements. In H the movement began at 12^h 20^m with a bay which reached its minimum at 12^h 42^m and then rose sharply to a peak at 12^h 59^m, then gradually falling to approximately normal value by 13^h 50^m. Ranges: D, 23′.9; H, 107 gammas; Z, 135 gammas.

March 1 2—This major magnetic disturbance began with a sudden commencement in all three elements. At 03^h 57^m 20^s GMT, March 1, the horizontal intensity almost instantaneously increased by 19 gammas and almost immediately after returned to approximately its former value. At 03^h 55^m 55^s the westerly declination decreased by 2′.4 and immediately afterwards increased by 8′.1. At 03^h 56^m 00^s the numerical value of vertical intensity decreased by 8 gammas and immediately afterwards increased by 29 gammas. Within one and one-half hours after this sudden commencement the traces became violently disturbed. By 08^h the westerly declination had decreased to about 40′ below its normal value. The horizontal intensity, by a series of rapid movements, had also diminished and the vertical intensity had so increased that, by 10^h 20^m it had reached the limits of registration. After 13^h 30^m the fluctuations in all three elements became still more violent and the vertical-intensity spot passed beyond the limits of registration between 15^h 30^m and 17^h 10^m. At 16^h 14^m, the horizontal intensity reached a minimum value 520 gammas below normal and the westerly declination at 17^h 06^m showed a value 36′.5 above normal. At 19^h the storm suddenly moderated very considerably and from then on the movements of the traces gradually subsided. Although it is hard to designate a definite time for the end of the storm, since the ensuing three or four days are all slightly disturbed, the traces had more or less regained their normal recording positions by the end of March 2. Ranges: D, 76′.8; H, 658 gammas; Z, more than 350 gammas.

March 13-14—During the magnetically disturbed conditions which prevailed during the twenty-four hours beginning at 16^h GMT, March 13, there was a period of activity between 12^h and 13^h, March 14, which merits notice. Between 12^h 13^m and 12^h 33^m H increased by 116 gammas and then, by 12^h 49^m, decreased by 79 gammas. Between 12^h 20^m and 12^h 37^m the westerly declination decreased by 17′.7 and then increased by 10′.0 by 12^h 49^m. Between 12^h 20^m and 12^h 37^m the numerical value of vertical intensity decreased by 133 gammas and by 12^h 50^m increased by 70 gammas. Ranges: D, 21′.0; H, 149 gammas; Z, 162 gammas.

March 28-31—Soon after 00^h GMT, March 28, the traces became moderately disturbed, all three elements showing long, sweeping fluctua-

tions, the greatest activity being between 09^h and 16^h, March 28. During March 29 the disturbance moderated somewhat, although the day was by no means quiet. These conditions continued until 10^h, March 30, when the activity again became more pronounced. At $16^h\ 37^m$, March 30, there was a very sudden large increase in H of 58 gammas, of the type usually associated with a sudden commencement. Sharp movements were also shown in the D- and Z-traces, but of much smaller amplitude. The traces continued to be disturbed, between 01^h and 08^h, March 31, the movements being of short period and small amplitude. Between $10^h\ 20^m$ and 12^h, March 31, there was a series of waves of large amplitude (the range in H over this period being of the order of 120 gammas) and a similar series, though much smaller between $17^h\ 10^m$ and $17^h\ 30^m$. After this time normal conditions were rapidly resumed and by 24^h, March 31, the traces were again "quiet." Ranges: D, 32′.5: H, 185 gammas; Z, more than 194 gammas.

W. C. Parkinson, *Observer-in-Charge*

Magnetic Observatory, Capetown

October to December, 1940

(Latitude 33° 57′ S., longitude 18° 28′ or $1^h\ 13^m.9$ E. of Gr.)

September 30-October 1—Disturbance began at 19^h GMT, September 30. Marked bays developed on all traces at 01^h, October 1, but otherwise the fluctuations were not large. At $11^h\ 54^m$ the disturbances became more marked and continued until 22^h. H decreased 121 gammas in the period from $01^h\ 52^m$ to $18^h\ 00^m$, while the decrease was 86 gammas from $15^h\ 01^m$ to $18^h\ 00^m$.

October 3—Bays appeared on all traces at 18^h GMT, October 3. The magnitude of the H-bay was $+38$ gammas in forty minutes and then -20 gammas in sixty minutes.

October 6-7—There was a small sudden commencement at $09^h\ 50^m$ GMT, October 6. There were slow, sweeping changes of the nature of bays up to 02^h, October 7. The amplitude of H-bay at $01^h\ 15^m$ was $+35$ gammas in forty minutes and then -16 gammas in forty minutes.

October 7 9—Disturbance increased at $08^h\ 50^m$ GMT, October 7, and continued until 01^h, October 9. From 09^h to $15^h\ 15^m$, October 7, H decreased 131 gammas, and from $15^h\ 15^m$, October 7, to $03^h\ 00^m$, October 8, increased 119 gammas. From $20^h\ 10^m$ to $20^h\ 45^m$, October 7, H, increased 81 gammas. There were bays on all traces at $23^h\ 10^m$, October 8. The magnitude of the H-bay was $+57$ gammas in thirty minutes and then -53 gammas in eighty minutes. Range: H, 121 gammas.

October 15—There were small disturbances from $00^h\ 20^m$ to $23^h\ 10^m$ GMT, October 15.

October 16—There were bays on all traces at 18^h GMT, October 16. The magnitude of the H-bay was $+31$ gammas in forty-five minutes and -28 gammas in thirty-five minutes.

October 18-20—The disturbance which began at 07^h GMT, October 18, lasted for about 48 hours. There were bays on all traces at $20^h\ 15^m$, October 18. The magnitude of the H-bay was $+35$ gammas in fifty minutes and then -28 gammas in fifty-five minutes.

October 21-22—Disturbance began at $09^h\ 20^m$ GMT, October 21,

and continued for 21 hours. There were bays on all traces starting at $20^h\ 15^m$. The amplitude of the *H*-bay was +36 gammas in thirty-five minutes and then −17 gammas in twenty-five minutes.

October 25-28—Rapidly changing disturbances began at 10^h GMT, October 25, and continued until 22^h, October 28. The range in *H* on October 26 was 145 gammas. There were bays on all traces at 20^h, October 28.

November 4-5—Disturbance began at 08^h GMT, November 4, and continued until $13^h\ 20^m$, November 5. The range in *H* was 119 gammas on November 4.

November 9—The range in *H* was 88 gammas.

November 12-18—Disturbances began at 08^h GMT, November 12, and continued until 12^h, November 18. The ranges of *H* were of the order of 70 gammas.

November 19-December 5—There were small disturbances throughout the whole of this period. Periods of greater intensity were from 09^h, November 19, to 16^h, November 23; from 09^h, November 25, to 20^h, November 26; from $21^h\ 40^m$, November 28, to 05^h, December 5. Ranges in *H* were: November 21, 110 gammas; November 22, 84 gammas; November 23, 89 gammas; November 24, 27 gammas; November 25, 127 gammas; November 29, 101 gammas.

December 10-16—The whole of this period was disturbed. The range in *H* was 91 gammas on December 10. On December 13 *H* decreased 48 gammas from $08^h\ 40^m$ to $09^h\ 40^m$. The range of *H* was 83 gammas on December 14 and 76 gammas on December 16.

December 20-24—A gradual-commencement storm began at about 01^h GMT, December 20. It developed into a large storm which continued until 07^h, December 24. The range in *H* was 135 gammas on December 20. Large bays accompanied by rapid oscillations were apparently on all traces during this period.

December 27-January 1—Disturbance began at about 11^h GMT, December 27, and continued until 02^h, January 1. There were sudden outbursts at $04^h\ 25^m$, December 30, and at $22^h\ 15^m$, December 31.

A. Ogg, *Magnetic-Survey Adviser*

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